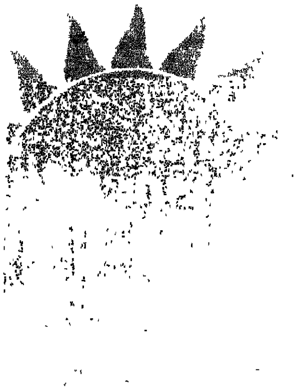

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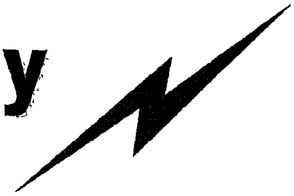

Solar photovoltaic applications

Forewords
R K Pachauri
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Editors
Shirish Sinha
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teri

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Foreword

The photovoltaic (PV) technology programme in India has undergone several changes in terms of technology, approaches to promotion, financial arrangements, etc. Numerous training programmes have been conducted in the past to equip extension agents, workers of non-governmental organizations (NGOs), and other stakeholders with advancements made in the PV sector. As part of such efforts, numerous documents have also come out as informational packages, dealing with specific issues in the sector – technical, financial, operational and maintenance, etc. However, there is lack of a comprehensive document that provides all information related to applications of PV technology, approaches to dissemination, financial arrangements, and institutional and social factors in technology acceptance, etc. beneficial to implementing agencies, financial organizations, and other stakeholders in the PV sector in India.

The present book, *From sunlight to electricity: solar photovoltaic applications*, a joint effort between Winrock International - India and TERI, is an attempt in this direction. It compiles information that gives the reader an overall understanding of the PV sector in India, designs and applications of specific devices and related benefits, finance, policies, and programmes. The book is not only a compilation of information, but also gives a step-by-step methodology for designing PV systems for appropriate applications in rural areas. The book has been written in a simple language with numerous illustrations such that readers not very familiar with the PV sector find the contents easy to understand. For others, the book aims at providing guidelines on sizing and installing PV systems, which they will find very useful in their work. This volume is expected to be of interest and importance to all the stakeholders in the PV sector, namely, policy makers, government officials, NGOs, academic and research organizations, etc.

R K Pachauri
Director, TERI

Foreword

Solar photovoltaics (SPV) is a simple, reliable, and environmentally-benign technology, providing electricity to widely dispersed households and settlements, which are often not even connected to the grid. India, with a photovoltaic (PV) potential of 20 MW/m^2, is the second largest manufacturer of SPV panels based on single crystalline solar cells in the world. Today, over 17 companies are engaged in the production of solar cells and modules and another 70 in the design and supply of SPV systems, aggregating to about 37 MW installed in the country.

However, despite being the most promising technology of the future, its highly capital-intensive nature, provision of government grants and subsidies, poor service after sales, and low awareness among potential PV market segments continue to be major barriers to its commercialization.

The Renewable Energy Project Support Office (REPSO) of the Winrock International - India has been promoting economically attractive and environmentally sustainable renewable energy applications. In its efforts to address the 'low awareness' barrier, under a United States Agency for International Development-supported Renewable Energy Commercialization (RECOMM) Project, it initiated a series of 'PV Awareness' workshops and meetings targeting industry; non-governmental organizations; and finance, housing, defence, and health sectors in collaboration with other organizations.

Also, to facilitate access to information on SPV, a comprehensive, but clear and descriptive, document on SPV for circulation at these programmes was required. This document, produced with the help of TERI, describes PV systems, their application, design and costing, case studies, along with a general overview of the SPV programme in India.

We sincerely hope that this publication will enthuse the select target groups to further the objective of SPV commercialization in India for a sustainable future.

Shyamala Abeyratne
Country Director
Winrock International - India

Preface

Electricity is one of the most vital energy sources for economic activities. The economic development of a country by and large depends on its efficient supply. It can help in transforming the way people live and work. In India, the rural electrification programme started in the 1950s with the aim of promoting economic development and improving the quality of life in rural areas. However, the impact of the programme has been very low. Scattered households in rural areas and the high cost of extending grid electricity supply to these areas have been identified as reasons. Installations of solar photovoltaic (SPV) systems for small-scale electricity generation directly from sunlight can help improve activities in domestic, health-care, agriculture, education, micro-enterprises sectors. SPV systems have been considered as one of the best options for rural infrastructure projects in electrified/un-electrified areas.

This document compiles information on several aspects ranging from the history of the technology to its principle, components, applications, advantages, and its limitations. It gives a step-by-step methodology of designing a PV system for appropriate applications in rural areas. The specific applications considered are domestic lighting systems and pumping systems. It also carries lists of system manufacturers and integrators, financial institutions and intermediaries, and state nodal agencies with their communication addresses.

The document contains seven chapters. The first chapter introduces PV technology, its principles, benefits and limitations, and the efforts of the government to popularize the technology in rural areas. The second chapter explains the components of a PV system. Chapter III discusses the applications of various PV systems, namely, domestic lighting systems, solar lanterns, street lights, PV pumps, and refrigeration. Chapter IV deals with designing of a PV system for various applications. In Chapter V, the costing of PV systems has been described. Other information includes market prices of systems/components, central government subsidy, credit facility extended by the Indian Renewable Energy Development Agency (IREDA), and the procedure to process soft loans. Chapter VI gives valuable tips on the operation and maintenance of PV systems. Efforts made by the government to promote PV technology are given in Chapter VII. This chapter also discusses the market development approaches adopted by various agencies such as IREDA–World Bank and non-governmental organizations to disseminate PV systems in rural areas. The latter has been discussed in the form of specific case studies.

The document helps a novice understand the technology and appreciate its various applications. It will also help those who are already familiar with the technology as it carries guidelines on sizing and installing PV systems in rural areas for appropriate applications.

Editors

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We would like to express our sincere gratitude to the Renewable Energy Project Support Office (REPSO) of the Winrock International - India for providing us an opportunity to undertake this project. We would like to thank Dr Shyamala Abeyratne, Country Director, Winrock International - India, for providing her valuable inputs. We are indebted to Ms K Usha Rao, PV Programme Officer, REPSO-India and Dr B S K Naidu, former Director, REPSO-India for initiating this project idea and for their valuable support and encouragement throughout the project. The inputs from Mr Rahul Arora, PV Programme Officer, REPSO-India and Ms Anita Khuller, Programme Development Officer, REPSO-India have been of immense help to us.

We gratefully acknowledge the United States Agency for International Development for providing financial assistance and support to the Renewable Energy Commercialization Project and for bringing out this publication.

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Special mention must be made of colleagues from the Publications Unit, who copy-edited, typesetted, designed, and supervised the production and publishing of this document. Colleagues from the Documentation and Information Centre did the indexing for the book. Ms Pratibha Shukla and Mr Arun did the artworks. Finally, a special thanks to Ms Poonam D Saxena for diligently word-processing the several drafts of the document.

I

Introduction

Background

Electricity is one of the most vital energy sources for economic activities. The economic development of a country by and large depends on its efficient supply. It can help in transforming the way people live and work. In India, although 87% of the villages have been electrified, only 31% of the households have access to electricity. In most of the rural areas, the households are scattered and these are not connected by grid electricity. A low demand for electricity, coupled with the high cost of supplying the grid electricity to these rural areas, has resulted in the very low impact of the rural electrification programme. This warrants a need for rural electrification with decentralized energy technologies, which provides alternatives to the sectors – domestic, health-care, agriculture, education, micro-enterprises, and community development.

Several technologies have been developed and have matured over time to meet the requirements of these sectors. The development of solar photovoltaic (SPV) systems for small-scale electricity generation directly from sunlight has helped to improve the activities in these sectors. A photovoltaic (PV) system can be installed at the site and does not require grid connection. It does not require the kind of infrastructure (such as the construction of a large power plant) that is required in the case of coal, oil, or gas. India has a large programme for PV systems, which include domestic lighting, portable lighting, street lighting, water pumping (agriculture and drinking water), and health and telecommunication sector. PV systems become an attractive option in the rural areas, where there is no electricity grid and electricity from diesel generators is either expensive or is not available. However, the high capital cost of the PV systems and the high per unit cost of electricity, when compared to diesel generators, have remained a major barrier for its large-scale dissemination. Although the rural populace is not very familiar with the PV system, it is expected to gain wide acceptance once it is introduced. The dissemination approach can be strengthened further by imparting appropriate training to the users and by developing a local infrastructure for easy repair and maintenance.

Solar photovoltaic programme in India

The Indian PV technology programme was initiated in 1976. The Ministry of Non-conventional Energy Sources (MNES) started a country-wide programme on the 'demonstration and utilization' of SPV systems for various applications in the early 1980s. The most common systems included:

- stand-alone street lighting systems;
- water pumping systems
- domestic lighting system;
- community televisions;
- power plants for centralized village electrification; and
- telecommunication systems.

The costs were shared between the central and state agencies: the MNES paid for the cost of the PV modules and the state agency met the expenditure on balance of systems (BoS) and local works.

The PV programme in the country received a major boost in 1992 when the Indian Renewable Energy Development Agency Limited (IREDA) established a revolving fund offering affordable credit for the purchase of PV systems. During the implementation year 1997/98, 1134 street lighting systems, 11 865 home lighting systems, and 31 380 solar lanterns were installed by February 1998 (MNES 1998). The MNES is also implementing a special programme (along with IREDA) on PV water pumping systems for agriculture and related use. A cumulative total of 2409 water pumping systems has been installed by the end of February 1998 under this programme (IREDA 1998).

Solar photovoltaic system

Photovoltaic refers to the creation of voltage from light. SPV systems directly convert sunlight into useful electricity. This process is called the photoelectric effect. The energy generator in a PV system is the solar cell. Solar cells are essentially thin wafers of silicon. These cells when connected in series and parallel constitute a solar panel. The two types of solar panels popularly in use are: (1) crystalline silicon cells and (2) thin-film cells. Currently, all the PV panels manufactured and sold in India are composed of single crystalline silicon cells. Depending upon the output load, one or more solar panels may be required. A series of these panels form a solar array.

The electricity [direct current (DC)] generated from these solar cells are stored in a battery. Between the battery and the loads, Charge controllers or electronics are provided. These prevent the overcharging or discharging of batteries by regulating the flow of electricity. Compact fluorescent lamps (CFLs) are normally used as lighting loads. Other loads are electrical devices, which operate on DC or alternating current (AC). In case of AC loads, inverters are used.

History of PV cells

The principle of PV cell was discovered in 1890. However, the first application of the technology was in the 1950s in the US, where these cells were used to power space ships. The oil crisis of the mid-1970s triggered research in PV technology for other applications, and the first PV industry was established in the early 1980s in the US.

In India, the first PV manufacturing industry was started by the Bharat Heavy Electricals Limited in 1983. In 1987, the Central Electronics Limited, a public sector undertaking (PSU) also started manufacturing PV panels. The early applications mainly included PV street lighting. At present, in addition to PSUs, there are private companies which manufacture solar cells and other system components. These companies are also into system integration.

Applications of PV systems

The electricity generated by the photoelectric effect can be either used directly or can be stored in batteries or can be directly fed into an electric utility's grid system. The energy stored in the battery (in the form of chemical energy) can be used to operate any electrical device. If the device operates on DC, then it can be directly connected to the output load. If the device operates on AC, then an inverter is required to convert DC into AC.

In India, the early applications of the technology were in the form of street lighting systems. In the past five to six years, there has been more emphasis on PV domestic lighting systems and PV water pumping systems for rural areas. PV systems have also found application in telecommunications and railway signalling.

The most common PV systems comprise lighting systems. These could be for indoors and/or outdoors. The indoor lighting systems include both fixed lighting systems, often called domestic lighting systems, and portable lighting systems or solar lanterns. The outdoor lighting systems are the street lights, garden lights, etc. In the agriculture sector, irrigation with PV pump (DC pump) is a common application. PV pumps are also used for lifting water for drinking purposes.

For rural areas, especially in off-grid areas, PV systems are most suitable. Health-care facilities in such areas are poor and there are often shortages of essential supplies, particularly of vaccines, owing to lack of refrigeration facilities. Solar refrigerator is a possible solution to overcome these problems. Other

Box 1. Applications of PV technology

- Individual systems for home: lights, TV and radio
- Portable lighting systems for home, agricultural fields, educational institutions, health centres, etc.
- Water pumping for irrigation and drinking water
- *Refrigeration*
- Battery-charging station
- Rural telecommunication
- PV integrated buildings
- Off-shore oil drilling stations
- Navigational systems
- Railway signalling.

applications of PV systems include crop sprayers, powering water purifiers by solar energy, and charging of radio and TV batteries by setting up battery-charging stations. In addition, the technology is being used in conjunction with other power generating devices such as diesel or wind electricity generators to design PV hybrid systems.

The type of applications of PV technology is varied (Box 1). However, selected applications are being discussed in this document. More specifically, applications at the household level or in the agriculture sector are given special focus. The various PV systems and their applications have been discussed in Chapter III.

Advantages and disadvantages of a PV system

Photovoltaic technology has been identified as one of the most environment-friendly technologies. A PV system can be used not only as a stand-alone system, but also to form a local grid. One of the major advantages of a PV system is that it requires only sunlight and no other energy fuel. Such systems can operate during direct sunlight as well as in diffused sunlight (monsoons and winters) conditions. Being modular in design, the capacity can be increased to meet additional demand. It is easy to dismantle and reconfigure these systems for other applications. PV systems require little maintenance. The regular maintenance usually involves topping up the batteries, occasional cleaning of module surface, and checking the electrical connections. Another advantage of PV systems is that the components can be manufactured and assembled locally. This increases the scope of income generation activities in the rural areas. The benefits of using SPV systems are listed in Box 2.

Box 2. Advantages of PV systems

- Environment-friendly as they do not emit gaseous and liquid pollutants.
- Noise free.
- Can be easily transported, assembled, and installed in remote areas.
- Robust, reliable, and weatherproof and have a long life.
- Produce DC electricity, which can be easily stored in a battery.
- Low maintenance costs.
- Zero fuel usage.
- Modular (systems can be expanded, if required).

Despite these advantages, PV systems have also certain limitations. One of the major drawbacks of a PV system is its high capital cost. This high capital cost makes the system cost-prohibitive. Further, only a few types of electrical devices can be operated using PV, as the nature of electricity is DC. This results in PV systems being less competitive compared to other alternative sources of electricity such as diesel or kerosene generators and battery inverter. Diesel/kerosene generators and battery inverters require similar investments, but are compatible with a wide range of electric devices. Except for the PV panel, the life of the system components is limited, which means that these have to be replaced after a certain number of years, putting additional financial burden on the consumer.

Higher potential of these systems is mainly in the remote rural areas, which do not have access to any source of electricity. Moreover, there is a low level of awareness about such systems. Although PV systems need very little maintenance, but in case of repairs, speedy redressal is a problem as no maintenance infrastructure exists at the grass-roots level. From the environmental perspective, disposal of the used batteries is also a major problem (Box 3).

Box 3. Limitations of PV systems

- High initial cost.
- Not always the best source for meeting large requirements.
- Repair and maintenance facilities are not readily available.
- Reliability of BoS: components other than the solar panels still require lot of improvements.

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II

Components of PV systems

Introduction

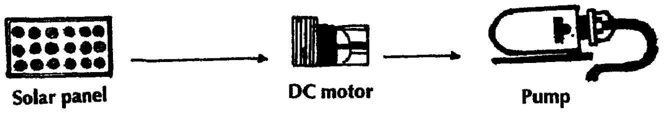
A solar photovoltaic (SPV) system is an energy generating system, which provides power for different types of devices. PV systems are classified into two types – one that provides power generated directly from the solar panels, and the other, where energy generated is stored and utilised when required. Thus, the usage of power generated either directly or in stored form depends on the type of application. Figure 1 illustrates the two types of system configurations. In the first configuration, power generated is used to operate the load directly. In the second, power generated is stored and used according to the demand, i.e., during low sunshine and/or non-sunshine hours. The most commonly used storage systems are batteries. Charge controllers are added to the system to prevent overcharging or over-discharging (also called deep discharging) of the batteries, which would affect their performance and life. Depending upon the type of load required to be operated, an inverter may be added to the system, which converts direct current (DC) to alternating current (AC) (as in the case of AC submersible pumps).

Irrespective of the system configuration, an SPV panel is the basic component of any system. The main building blocks of a PV panel are the solar cells. All components in the system, other than the panel and loads, are termed as Balance of System (BoS). The BoS comprises batteries, charge controllers, inverters, and other accessories. The final configuration of a PV system depends upon the site location and specific load requirements.

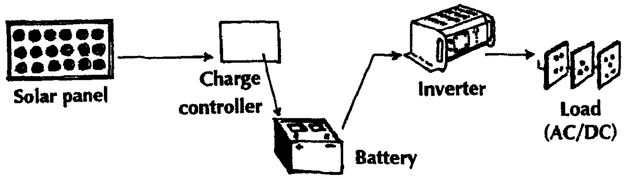
Solar cells

The fundamental power unit of a PV system is a solar cell. It is a semiconductor generally made of silicon. A solar cell is a thin wafer, which is chemically treated and processed at high temperatures. Many such wafers are joined together to create a *p–n* (positive–negative) junction, across which voltage develops when sunlight falls on these cells (Figure 2). The four common types of silicon photovoltaic (PV) cells are listed below.

- Single crystalline silicon
- Polycrystalline silicon



a) direct conversion system



b) storage system

Figure 1. PV system configuration

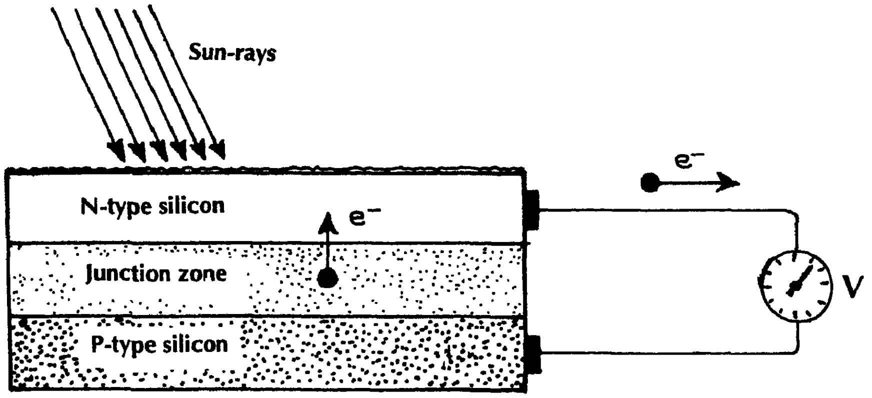


Figure 2. Working principle of a solar cell

- Ribbon silicon
- Amorphous silicon

Most PV cells are of the single crystalline type (Figure 3). To produce these, silicon is purified, melted, and crystallized into ingots. These ingots are sliced into thin wafers to make individual cells. Individual cells are attached to a base called a 'back-plane', which is usually a layer of metal used to physically reinforce the cells and provide electrical contact at the bottom. Polycrystalline cells are manufactured by a similar process using low quality silicon. In the case of ribbon type PV cells, molten silicon is drawn into a ribbon. In contrast to other types of cells, the amorphous silicon does not have any structure. These cells are made by depositing thin layers of vapourized silicon in vacuum on a back-plane, generally made of glass.

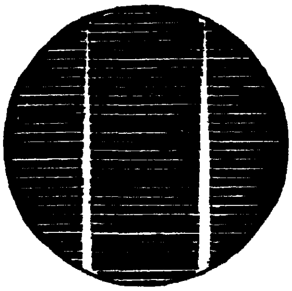


Figure 3. A solar cell

Solar photovoltaic panel

The power output of a single solar cell is too low to operate most electrical devices (most cells produce a voltage of about 0.5 V, regardless of the surface area of the cell). Therefore, many cells are connected in series to increase the voltage. Several series of cells can also be interconnected in parallels to increase the power output.

Solar cells are extremely fragile. To protect them from damage, they are hermetically sealed between a top layer of glass or clear plastic, and a bottom layer of plastic or a combination of plastic and metal. An outer frame is attached to increase the strength, and this whole package is called a PV panel. At the back of the panel, a junction box is provided to extract electricity (Figure 4). Depending upon the load and battery requirements, the panels are connected in series/parallel combinations and mounted on a metallic frame. Such aggregates of PV panels form a PV array. In India, most of the PV panels available in the market are either mono or polycrystalline silicon type. Table 1 compares the characteristics of amorphous and crystalline silicon panels.

The SPV panels are rated in terms of *peak watt* (W_p) units. The term 'peak hours' denotes the minimum number of hours of sunlight required to produce a desirable amount of electricity daily. The solar insolation of a region indicates

Table 1. Characteristics of crystalline and amorphous silicon panels

Crystalline PV panels	Amorphous silicon panels
High quality cells with no change in performance levels	Not very stable and the performance level decreases to half within a year
High efficiency (13%–16%)	Very low efficiency (5%–8%)
Long life (more than 20 years)	Short life (less than 10 years)
Does not wear out	High wearing out possibilities

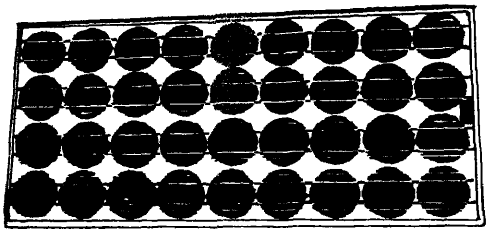


Figure 4. An SPV panel

the total hours for which the rated 'peak watt' from a panel can be obtained. In India, the most commonly used panels are rated as 35 W_p (domestic lighting systems, pumping, etc.), and 10 W_p for portable lighting systems (solar lanterns). The other panels available in the market are 50, 70, and 100 W_p. The average solar insolation in India is 5.2 kWh/m^2/day.

The performance parameters are expressed in terms of standard solar conditions: an ambient temperature of 25 °C, and an insolation of 1000 Wh/m^2. The power output from a panel depends upon the ambient temperature, solar insolation or radiation, and the location of the site. The power output of the panel decreases with increase in ambient temperature. Against each unit (W_p) of rated power, the panel should produce about 0.85 Wh of electrical energy for each unit (kWh/m^2/day) of solar insolation. For example, a 35 W_p panel would produce 35 × 0.85 Wh = 29.75 W of electricity under standard solar conditions in India.

Balance of Systems

All system components other than the PV panel are termed as the BoS. The most critical component of the BoS is the battery. This is used when the system is to be operated during non-sunshine hours or if the loads operate on DC. The other components include charge controller, inverter, and supporting electrical and physical equipment.

Batteries

Battery is the most frequently used storage device in SPV systems. Batteries store the electrical energy generated by the panels during sunny days, and deliver it during cloudy days or non-sunshine hours when solar power generation is low or not possible. Battery needs DC for charging. The electricity generated from solar cells is also DC, which can be easily stored in the battery, without involving any intermediary process (Figure 5). Battery capacity is expressed in terms of voltage (V) and ampere-hour (Ah).

The batteries are recharged to 100% capacity during the charging phase of each cycle. A cycle is described as an interval that includes one period of charging

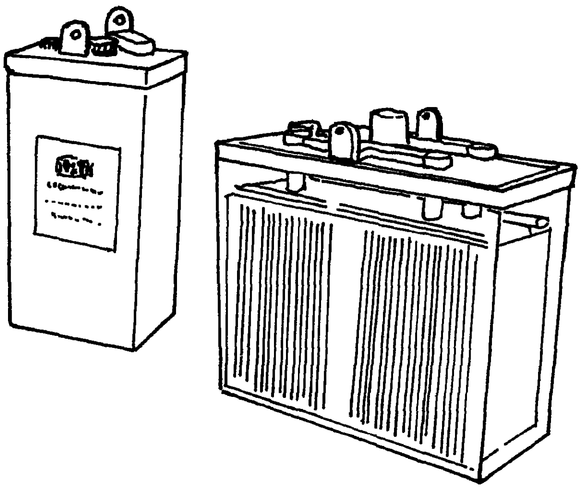


Figure 5. Battery in PV systems

and discharging. However, the batteries must not be completely discharged during each cycle. If a charge controller is not included in the system, oversized loads or excessive use can drain the batteries' charge to the point where they can be damaged and have to be replaced. Similarly, the controller regulates overcharging of the batteries that can be damaged during times of low or no use or long periods of full sunshine hours.

Two types of batteries are used with PV systems – lead–acid batteries and nickel–cadmium batteries. In India, however, the most commonly used batteries are lead–acid batteries. Lead–acid batteries are further classified into flooded and dry cell. In most of the domestic or large-scale applications of PV systems, flooded lead–acid batteries are used. Dry cell batteries are used in portable lighting systems such as solar lanterns. The dry cell batteries are of 7 Ah, while the flooded batteries are available from 40 to 100 Ah.

PV batteries are deep discharge batteries as compared to shallow discharge autompbile batteries. The critical performance parameters for PV batteries are storage capacity, charging and discharging efficiency, self-discharge, capability to operate in different state of charging modes, and operation and maintenance procedures (see Chapter VI). The battery efficiency for most PV applications is 85%. Depending upon the load size, one or more batteries may be required. Such an aggregate of batteries is called a battery bank.

Inverters

Photovoltaic systems work more efficiently with DC loads (as there are no conversion efficiency losses), however, certain applications or AC loads can also be operated with solar electricity using an inverter. Inverters are electronic components, which convert DC into AC. DC has a current flow in one direction only, while AC rapidly switches the direction of current flow back and forth. In a typical PV system, inverters are placed after the batteries and before the loads. They should be placed reasonably close to the battery bank but not inside the battery enclosure.

Charge controller

Charge controller is a solid-state electronic component, which controls the electricity generated by solar cells (Figure 6). A charge controller acts like a voltage regulator and is placed between the PV panel and the battery. The primary function of a charge controller in a stand-alone PV system is to manage the rate and amount of charging of batteries, and to protect the battery from overcharging or deep discharging. Absence of change controllers may result in shortened battery life and decreased load availability.

Blocking diode

Blocking diode is another type of charge controller device. This acts as a check valve to prevent discharge of batteries (reverse flow of current to the solar cells) through PV panel during night or during insufficient sunlight.

Other components

Other components of PV systems include electrical connecting and physical mounting equipment. Electrical connecting equipment comprises electrical wires connecting PV panels, and from panels to batteries, inverters, and loads. The physical mounting equipment comprises metallic frames, nuts, bolts, and clamps, which are used for roof-top mounting of panels or ground installation.

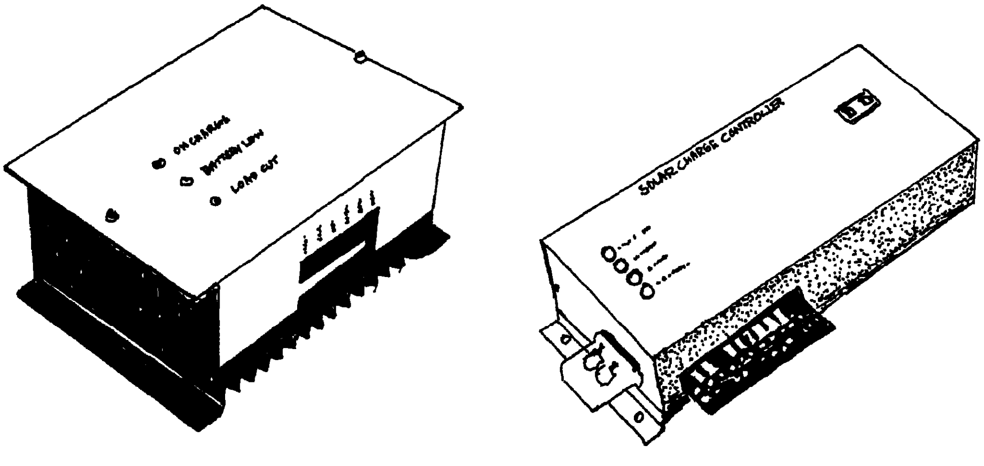


Figure 6. Charge controller

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III

Applications of PV systems

Introduction

Photovoltaic (PV) systems have diverse applications in the off-grid areas. Over time, with the advancement of PV technology, its reliability as a power source for numerous applications in the rural areas has increased. Household applications of PV systems are expected to benefit the rural people, thereby significantly improving their quality of life. The other main application of PV systems in rural areas is pumping groundwater for drinking and irrigation purposes. PV systems for refrigeration purposes have numerous benefits for the rural health sector where there is no storage facilities for essential medicines and vaccines. In rural telecom projects, PV systems have an important role to play by linking remote far-flung villages to the mainstream of national development initiatives.

The various applications of PV systems, especially in the rural context, include indoor and outdoor lighting systems, PV pumps for drinking water and irrigation, PV refrigerators for storing vaccines, and other applications (Figure 1).

Lighting systems

Lighting is one of the most common applications of PV systems in rural areas. Lighting systems are of two types – indoor and outdoor. Indoor lighting systems are further classified into fixed and portable. The fixed indoor lighting system is also called domestic lighting system (DLS) or solar home system (SHS). Portable indoor lighting systems are generally the solar lanterns. Outdoor lighting systems include street lights, garden lights, etc. However, with increasing demand for electricity for entertainment needs [e.g., use of television (TV)], the definition of DLS has changed from being a *two-light point system* to system with *double light points*, with an additional provision for operating a portable black and white TV or a fan.

Domestic lighting systems

Domestic lighting systems, as the name indicates, are designed to meet the domestic lighting requirements. Initially, most of the DLS were two-light point systems, but now additional loads like TV and fan are also being integrated with

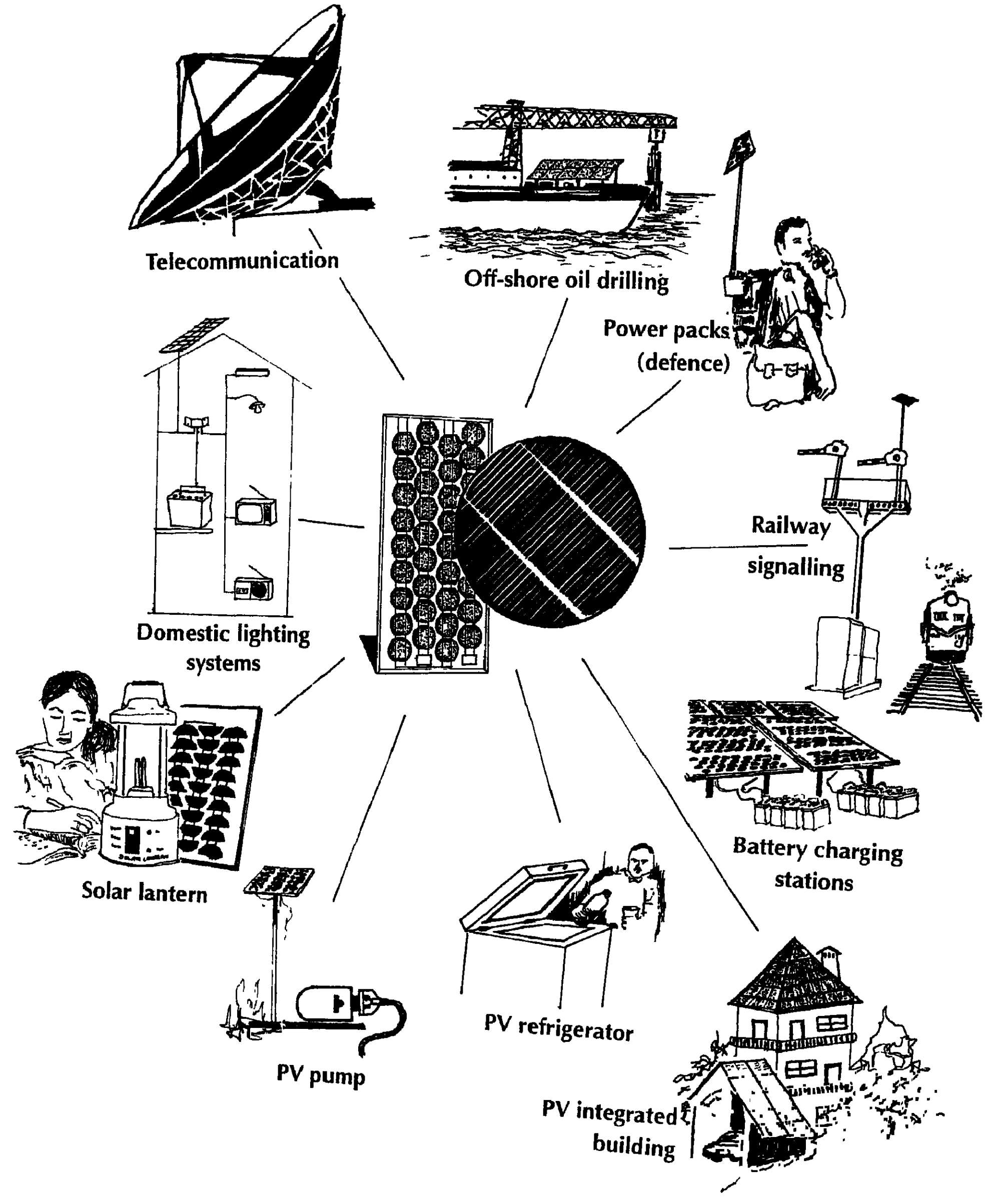

Figure 1. Applications of PV systems

Table 1. MNES specifications for DLS configuration

Configuration	Panel wattage (W_p)	Battery	Loads	Hours
I	One 35	One 12 V, 40 Ah	Two CFLs 9 W/ 11 W with or without a point for TV	Lights: 3–4
II	One 35	One 12 V, 40 Ah	One CFL 9 W/ 11 W; one DC fan	Lights: 1–2; Fans: 1–2
III	Two 35 or one 70	One 12 V, 75 Ah	Two CFL 9 W/11 W; one DC fan	Lights: 2–3; Fans: 2–3

Source. MNES (1997)

the system. The most common DLS is a 35 W_p system with provision for two light points. All the systems installed by the Ministry of Non-conventional Energy Sources (MNES) have to follow certain specified configurations. The MNES has proposed three configurations for DLS and incentive in the form of direct cost subsidy is available. Table 1 presents the DLS configuration as per MNES specifications. Figure 2 gives the schematic view of a DLS and the possible loads.

As the configurations mentioned in Table 1 qualify for the cost subsidy from MNES, these are the most widely installed systems. However, other system

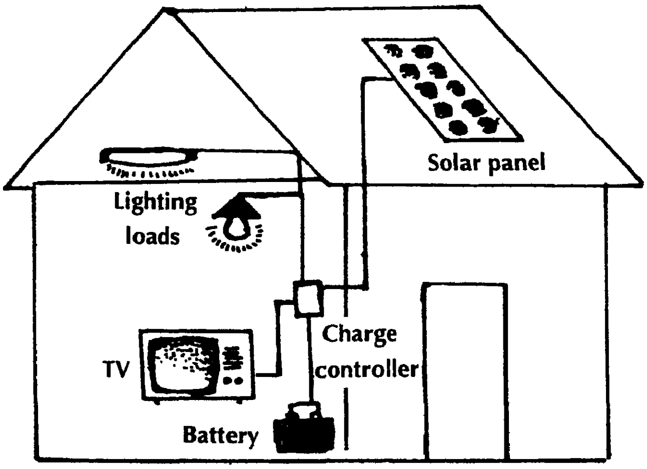

Figure 2. Schematic view of a DLS

configurations depending upon the overall load are also available. The components of a DLS are described below.

PV panel

The PV panel generally consists of monocrystalline solar cells. The power rating varies from 35 to 70 W_p, and this can be increased depending upon the load. The panel should be installed based on the optimal tilt angle and direction, either on the rooftop, or at a place where it gets maximum sunshine.

Battery

The batteries used in DLS are flooded electrolyte type lead–acid tubular batteries. Batteries have a rating of 12 V with either 40 Ah or 75 Ah discharge rate.

Lamps

Compact fluorescent lamps (CFLs), both 2-pin and 4-pin types, are used. The ratings of these CFLs are either 9 W or 11 W. In case of 4-pin type CFLs, a preheating circuit is provided. The CFL is placed in an assembly, often called luminaire, with a reflector on its back. Lamps are installed in a base-up position.

Electronic components

A charge controller and an inverter are provided with the PV system. The combined efficiency of both is around 80%. A blocking diode is also provided to prevent the reverse flow of current to PV panel from batteries, and a fuse is provided to prevent short-circuit.

Other loads

The other loads used with a DLS could be DC fan, portable black and white TV set, etc. The loads of both are in the range of 18–20 W.

Other components

Other components in a DLS include a metallic frame for installing PV panels on the rooftop. An acid-proof and corrosion-resistant vented metallic box is provided to store the batteries inside the house.

The DLS has two light-emitting diode (LED) indicators: a green LED indicator or indicate that battery is getting charged; and a red LED indicator to indicate that the battery has reached the discharge cut-off stage.

Solar lantern

Solar lantern is a single light point portable lighting system. Apart from the PV panel, it consists of a lamp, a battery, and electronic components, all placed in a casing, either made of metal, plastic, or fibreglass. Because of its portability, it finds both indoor and outdoor applications.

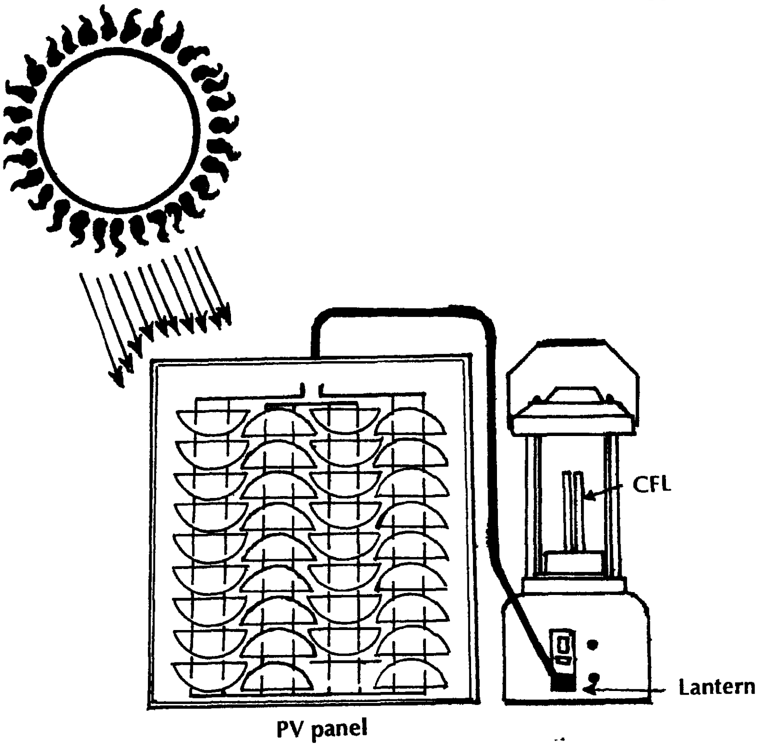

Figure 3. Schematic view of a solar lantern

Most of the solar lanterns radiate 360 degrees of light output. At present, limited unidirectional solar lanterns are available in the market. Figure 3 gives the schematic view of a solar lantern. The different configurations of a solar lantern approved by the MNES are given in Table 2.

A 5-W or 7-W CFL is used, which can either be a 2-pin type or a 4-pin type. If a 4-pin type CFL is used, then a preheating circuit is provided and the lamp is mounted on a base. The lumen output is generally in the range of 230 lumens (5-W CFL) to 370 lumens (7-W CFL).

Table 2. Solar lantern configurations approved by the MNES

Configuration	PV panel (W_p)	Battery	CFL (W)	Usage (hours)
I	8	12 V, 6.5 Ah or 6 V, 12 Ah	5	3–4
II	10	12 V, 6.5 Ah or 6 V, 12 Ah	5	3–4
III	10	12 V, 6.5 Ah or 6 V, 12 Ah	7	3–4
IV	12	12 V, 6.5 Ah or 6 V, 12 Ah	7	3–4

Source. MNES (1997)

Battery

A sealed, maintenance free, lead–acid battery or a tubular plate lead–acid battery with spill-proof feature is used. The minimum battery capacity is of 6.5 Ah at 12 V or 12 Ah at 6 V.

PV panel

The PV panel used in a solar lantern can have a power rating of 8, 10, or 12 W_p. Depending upon the latitude of the region, the module is installed at an optimum tilt angle on a rooftop or is placed where maximum sunshine is available. Normally, households do not install solar panels on rooftops, but they are kept in the sun daily.

Electronic components

An inverter with at least 80% efficiency is provided with the system. It also has a cut-off provision to prevent overcharging or deep discharging of the battery. A fuse is provided in the system to prevent short-circuit. Like DLS, solar lanterns are also provided with two LED indicators to indicate the charging and the deep-discharge state. Other accessories include a five-metre long wire extending from the panel to the lantern, and an ON/OFF switch.

Outdoor lighting systems

The most common and widely used outdoor lighting system is the solar PV (SPV) street light. Other applications include garden lighting, farm lighting, etc. which operate on the same principle.

PV street lights

Photovoltaic street lights are stand-alone systems with one or two panels, a lead–acid battery, and a luminaire with a CFL. They are available in two models depending upon the operating hours (Figure 4). One model is called *dusk to dawn*, which can be used for 12 hours. The second model has an operation time of 4–6 hours. Neon street lights can also be powered by PV panels. Table 3

Table 3. Commonly available PV street light models in the market

Configuration	PV panel (W_p)	Battery	CFL (W)	Hours
Model A	35 (one)	6 V, 60 Ah (one)	11 (one)	4–6
	70 (one) or	6 V, 100 Ah (two)	11 (two)	4–6
Model B	70 (one) or 35 (two)	6 V, 100 Ah (two	11 (one)	1–2
Model C	100	6 V, 120 Ah (two)	11 (two)	1–2

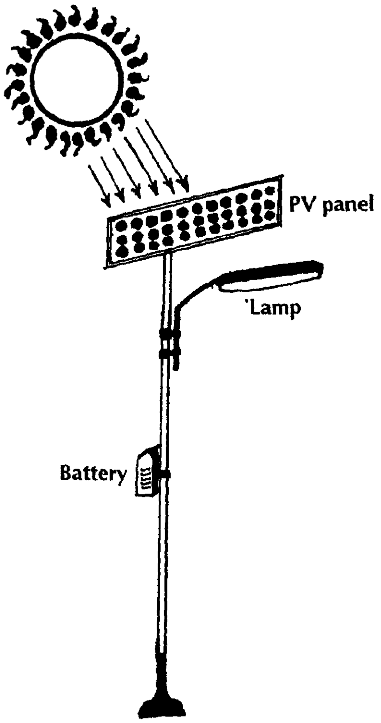

Figure 4. PV street light

presents the different model configuration of street lights. The MNES does not provide any subsidy for PV street lights.

Panel

Panels of 35, 70, or 100 W_p are generally used. The number of modules depends upon the load (number of CFLs) and the hours of operation (4–6 or 12 hours).

Battery

The lead–acid flooded battery is the most commonly used battery in PV street lighting system. The rating of the battery is 6 V with a capacity in the range of 100–120 Ah.

Lamp

In PV street lights, 11 W CFLs are used. They could be of 2-pin type and 4-pin type. In the 4-pin type CFLs, preheating circuit is provided. The lamps are housed in a weatherproof assembly with a high reflecting base. The lamps are fixed in a base-up configuration. The output from the lamps is around 900 lumens.

Electronic components

An inverter with a minimum 80% efficiency is provided with the system. It also includes a sensor for automatic switching (ON/OFF) of the light at a predetermined/fixed time interval (4–6 or 12 hours). It also includes protection from overcharging or deep discharging of the batteries.

Other components

The PV panels and the lamp are mounted on a steel pipe with a height of 4 m above the ground. A metallic, corrosion-proof box is provided to store batteries and a frame to mount the modules.

Refrigeration

As electricity is not available in most of the rural areas, the storage of important life-saving medicines and vaccines becomes a problem. Vaccines used in immunization programmes have to be stored at temperatures ranging from 0 °C to 8 °C throughout the stages of transportation and storage (the vaccine cold chain). In the mid-1980s, the World Health Organization (WHO)/United Nations Children's Fund's (UNICEF's) Expanded Programme on Immunization specified the use of PV refrigerators for vaccine transportation and storage wherever they are economically and technically justified. There are now about 5000 PV refrigerators installed worldwide, primarily in the developing countries.

The performance of refrigerators fuelled by kerosene and bottled gas is often inadequate. Diesel-powered systems frequently suffer from fuel supply problems. Thus, PV offers a reliable power supply solution for refrigeration without the need for refuelling, though they do have a higher initial capital cost. PV refrigerators can also be more economical to operate than kerosene refrigerators when examined on the basis of cost per potent vaccine dose. They are also preferred because of their greater reliability and freedom from fuel supply problems.

PV refrigerators operate on the same principle as normal compression refrigerators, but these have: (1) low-voltage (12 V or 24 V) DC compressors and motors; (2) high levels of insulation around the storage compartments to maximize energy efficiency; (3) a battery bank for electricity storage; and (4) a battery charge controller. Energy consumption per refrigerator ranges from as little as 0.15 kWh/day to over 1.0 kWh/day, depending on the capacity of the refrigerator, operating conditions, and the provision of a freezer. Operating norms are rigorous, as most vaccines must be stored between 0 °C and 8 °C in order to retain potency. It is mandatory for PV refrigerators to conform to the performance specifications laid down by WHO/UNICEF.

The output of a PV array varies according to the geographic location in which the system is to be installed because, the refrigerator's energy consumption depends on local climate. Hence, the size of the SPV array, the battery storage capacity, and consequently the system cost will depend on the geographic location. In India, SPV vaccine refrigerators have been installed in approximately 100 rural health centres. The capacity of these vaccine refrigerators is 50 litres (45 litres for vaccine storage and 5 litres for ice-making). A true comparison of solar refrigerators and kerosene and bottled gas fuelled refrigerators can only be made through a life cycle cost analysis.

PV refrigerators for domestic use are also available, which have lower technical specifications than medical refrigerators. Cold stores can be powered by PV. However, these systems are still in the R&D phase, and are very expensive.

Water pumping systems

Groundwater is considered the safest and the most reliable amongst traditional sources of clean potable water. Conventional techniques for drawing groundwater for drinking and domestic use involve the use of:

- mechanical energy provided by human beings and animals in conjunction with equipment, e.g., simple rope and bucket, handle or wheel with goatskin pouch, hand-pump, and foot-pumps; and
- animal energy to turn flywheels made of wood or metal, and use of diesel engine or electric motor-driven pumps.

Table 4 presents a comparison between various water lifting/pumping technologies. There has been a significant increase in the use of renewable energy technologies for water pumping in the last few years, mainly due to constraints (cost, availability of fuels, convenience, etc.) in the dissemination of conventional technologies. Technologies using hydro power, solar energy, wind energy, and biomass are being used as alternatives. Each of these technologies offers certain advantages over others, but their viability is linked to many parameters specific to the location.

PV water pumping systems consist of a PV array, motor, pump, optional power conditioning equipment (for conversion of DC to alternate current (AC), in case of AC pumps), and batteries (Figure 5). Two of the most economical applications of PV water pumping are for irrigation and drinking water supply. A special project was initiated in India, in 1984, to demonstrate and popularize the PV water pumping system under the National Solar Photovoltaic Energy Demonstration programme. The project covered the states of Andhra Pradesh, Bihar, Orissa, Tamil Nadu, Uttar Pradesh, and West Bengal. The programme was

Table 4. Advantages and disadvantages of various pumping technologies

Technology	Advantages	Disadvantages
Hand pumps	Local manufacture possible Easy to maintain Low capital cost No fuel costs	Loss of human productivity Often inefficient use of bore-holes Only low flow rates achievable Maintenance of animals require feeding all-year round
Hydraulic pumps	Unattended operation Easy to maintain Low cost Long life	Require specific site conditions Low output High capital cost in some cases
Wind pumps	Unattended operation Easy maintenance Long life	Water storage required for low-wind periods Intensive project planning needs Difficult to install
Solar PV	Unattended operation Low maintenance Easy installation Long life	High capital cost Water storage required for cloudy periods Repairs require skilled technicians
Diesel pumps	Quick and easy to install Low capital cost Widely used Can be portable	Fuel supply erratic and expensive High maintenance cost Short life expectancy Noise and air pollution
Electric motor-driven pumpsets	Low capital cost Easy to install Wide range of applications	Electricity supply erratic Poor quality of supply in rural areas

Source. IT Publications (1994)

coordinated by the Department of Non-conventional Energy Sources, which is now the MNES. By the end of February 1998, a total of 2409 PV water pumping systems have been installed in the country. The capacity of a water pumping system varies from 200–2250 W_p. The PV water pumping systems are being used for supplying drinking water, micro-irrigation, horticulture, and silviculture (Figure 6).

Drinking water supply

Under the Rajiv Gandhi Drinking Water Mission, PV systems were adopted on a large scale for supplying and distributing drinking water. Till February 1998, 195 PV pumps have been installed in different states. In the case of PV pumps for supplying drinking water, groundwater is lifted and stored in an overhead tank. Systems along with their capacities are designed based on the daily water requirement in a community or a village.

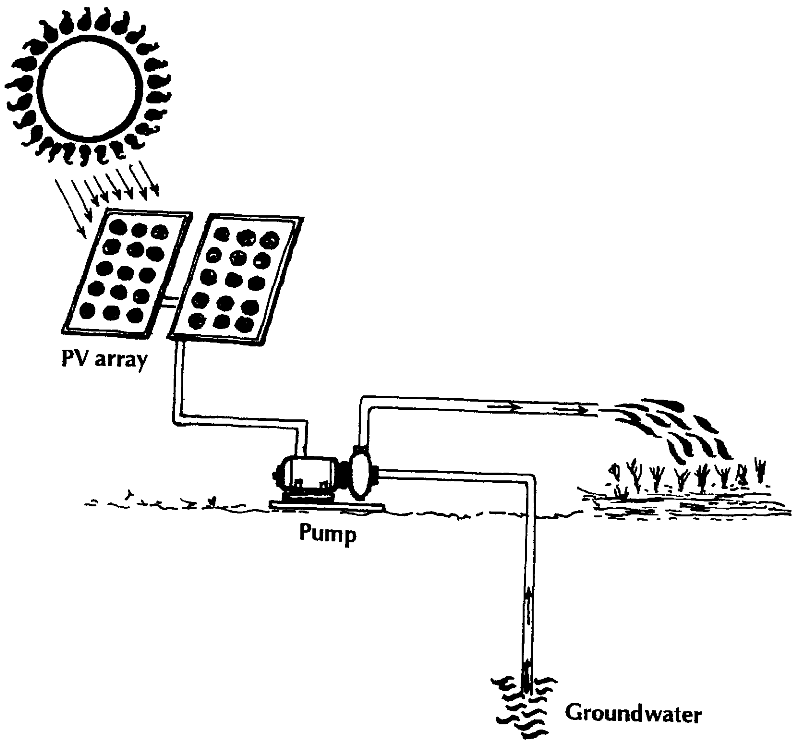

Figure 5. PV water pumping systems

Irrigation

Another common application of PV pumpsets is for lifting water for irrigation. The following types of pumpsets are used for irrigation.

- DC submersible pumpset
- DC surface-mounted centrifugal pumpset
- DC floating pumpset
- AC submersible pumpset

The discharge from the pump at a suction head of 7 m or the total head of 10 m is approximately around 15 000 litres/day from a 200 W_p panel and 170 000 litres/day from a 2250 W_p panel. The discharge varies with the intensity of the sun, and is at its maximum during noon. At the total head of 10 m, a PV pump can irrigate about 0.5–0.6 ha, but this again depends upon the water table, soil conditions, and water management.

The cost of PV pumping installations varies depending on the size, location, and other factors (such as labour and material costs). As with other PV systems,

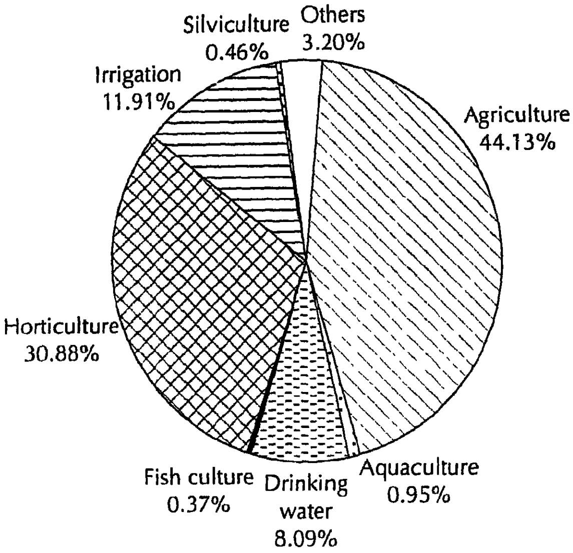

Figure 6. End-use wise distribution of PV pumps (%)
Source. Singh (1998)

the main cost of water pumping system is the initial cost. A typical PV pump would cost in the range of Rs 300 000/- to Rs 700 000/-, depending on site conditions. Clearly, the greater the pumping head or daily volume of water required, the greater the energy demand. Accordingly, the need for more panels. Panels form the major part of capital cost. However, once installed, very little maintenance is required. Hence, the annual recurring costs are lower.

Other applications

Battery-charging stations

There is a huge demand for supplying electric power to operate small torches (flashlights), radios, television sets, and lights in some remote areas. This is evident from the continuous transportation of batteries from rural areas to grid-connected towns (for charging), battery-charging services offered by numerous diesel generator (DG) set operators in the villages and small towns, and generation of vast quantity of small 'throw-away' primary cells bought by the rural households. For example, in Sundarbans, West Bengal, a family spends, on an average, Rs 12–15/- per month on dry cell batteries.

Battery-charging stations consist of a PV generator, normally between 500 and 1000 W_p, charges the batteries centrally. Batteries are then delivered or local household owners collect it. PV battery charging is very similar to DLS from a technical and economic point of view. Central charging stations are effective management systems for collecting fees or rentals, but the only drawback is the transportation of batteries (often perceived as a disadvantage by the users).

PV-hybrid systems

Photovoltaic systems generally have a provision for storing energy for a pre-defined period of insufficient sunshine. However, there may be exceptional periods of poor weather conditions when an alternative source is required to guarantee power production. In such cases, PV-hybrid system is an appropriate solution.

PV-hybrid systems combine a PV generator with another power source – typically a diesel generator, but other renewable energy sources such as a wind turbine or hydro can also be combined. The PV-hybrid system is usually sized to meet the base-load demand, with the alternate supply being used only when essential. This arrangement offers all the benefits of a PV system, such as low operation and maintenance costs, as well as ensures a more secured supply. However, the two advantages of a PV-hybrid system, i.e., simplicity and reliability, are negated by the addition of rotating machinery or over-complicated hybrid control logic.

PV-hybrid systems are suitable in areas where occasional demand peaks are significantly higher than the base-load demand. It is not viable to size a system to be able to meet demand entirely with PV if, for example, the normal load is only 10% of the peak demand. Likewise, a DG set, sized to meet the peak demand would be operating at inefficient part-load for most of the time. In such a situation, a PV-diesel hybrid would be an ideal compromise.

Other systems

There are a variety of other systems that can be powered by PV. These include data acquisition systems, remote monitoring stations, off-shore oil drilling, air conditioning, ventilation, broadcasting systems, telecommunications, railway signalling, and other consumer products.

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IV

Designing a PV system

Introduction

Photovoltaic (PV) system design primarily depends on the type of application for which the power generated from it will be used. If it is required for pumping water for agriculture or drinking water supply applications, the electrical storage device is optional and not generally recommended because of added costs. However, for devices which are operated during the evening or in the night, namely, lighting or refrigeration, an electrical storage device is a must.

The overall design of a PV system (number of panels and batteries) depends upon the total system load. The load for a PV system is governed by the appliances to be powered by the system. Indoor lighting systems typically include lights, fans, televisions (TVs), etc., and outdoor loads include street lights, water pump, etc. Solar PV (SPV) panels of varying wattage capacities are available in the market. Batteries, which are measured in terms of ampere-hours (Ah), are also available in different capacities. The basic information required to design a suitable system for different applications is presented in Table 1.

Table 1. PV system application and associated information requirements

Application	Information required
Lighting and other domestic applications	Number of lights/appliances required Wattage of each light/appliance Average daily usage of each device in hours Seasonal loads and number of monsoon months
Solar pump	Water source (river, canal, well, borewell, etc.) Characteristics of source (diameter, water available, etc.) Head (total head from which water has to be lifted) Water demand (monthly basis and also peak season demands) Water storage and distribution
Solar refrigerator	Size of the refrigerating unit (volume) Maximum amount of goods to be frozen or kept Normal ambient temperature

Designing a PV system with battery back-up

In order to design a PV system with a battery back-up, firstly the total load or daily energy consumption has to be determined. On the basis of existing or desired loads, the number of panels and the battery voltage required to meet the daily energy demand can be calculated. To ascertain the battery size and the required wattage of the panels, the peak load is calculated for such months when maximum number of devices would be used. In addition, the months during which the intensity of solar radiation and the duration of sunshine hours is lowest should be identified. In India, most of the systems are designed taking into consideration the winter months as well as an approximate number of rainy days during monsoons.

Measuring solar radiation

The performance of PV systems is a direct function of available insolation and the efficiency of the devices. With increased insolation and improved device efficiencies, system performance is enhanced. As the basic characteristics of any SPV module change with the variations in solar radiation, the foremost parameter to be considered prior to installing any PV system is the availability of adequate solar radiation.

The daily solar energy that a PV array is capable of producing depends on the insolation observed throughout the day and the size of the array capturing the energy. For calculating the appropriate array size, one needs to know the availability of solar insolation at the site. For convenience, monthly solar radiation is usually expressed in terms of the daily average solar insolation of the month.

Sunlight availability or insolation is measured in kWh/m^2/day. It ranges from an average of 3 to 7 kWh/m^2/day worldwide. India receives solar energy equivalent to over 5000 trillion kWh, which is far more than the total energy consumption of the country. Under clear sky conditions, the daily average solar energy incidence varies from 4 to 7 kWh, depending upon the location. There are about 250–300 sunny days in most parts of the country. For example, Varanasi and Allahabad region receive an average summer solar radiation of 6.8 kWh/m^2 and an annual average of 5.8 kWh/m^2. It is only during winters that the average falls to 4.8 kWh/m^2. And this occurs for less than 20% of the year.

Determination of load

To determine the load, a simplified procedure can be followed.

Step 1. Selection of units to be used
Step 2. Determination of wattage of each unit
Step 3. Determination of usage hours of loads
Step 4. Determination of total load

Selection of unit

Depending upon the requirement, units, whether lighting or other, are identified first.

Example. Let us assume that the total requirement of household is as follows.

- Lights: 3 points
- TV (black & white): 1 point
- Fan: 1 point [during summer (four months)]

Determination of wattage

The standard wattage for each electrical load is fixed. Table 2 provides the wattage of different electrical loads. In order to determine the system size, identification of the wattage of each electrical load is necessary.

Table 2. Wattage of different electric loads (AC/DC) for PV application

AC load	Wattage (W)
Fan	40/65
TV	
Black & white	18
Colour	40, 80, 120
Fluorescent tube	20, 40
CFL	
Solar lantern	5, 7
Domestic lighting	9, 11
Radio/tape recorder	5–20
Pump	200–2250 W_p
DC load	**Wattage (W)**
Fan	20
TV	18, 20
Fluorescent tube	20

Example. If compact fluorescent lamps (CFLs) are used for lighting in the example cited above, two CFLs of 11 W and one of 9 W are required. The requisite wattage for the household is given is Table 3.

Determination of usage hours of loads

For each of the loads identified, the requirement in terms of usage hours per day is calculated. Table 4 shows the usage (hours) of each unit in example household.

Table 3. Wattage requirement of example household

Load	Number	Wattage (W)
CFL	2	11
CFL	1	9
TV (black & white)	1	18
Fan	1	20

Table 4. Usage hours of loads in example household

Load	Number	Wattage (W)	Hours/day
CFL	2	11	5
CFL	1	9	3
TV	1	18	5
Fan	1	20	8

Total load determination

The total load is expressed in terms of watt hours/day (Wh/day). This is determined by multiplying the number of devices with their respective wattage and the number of hours used per day.

Example. For the example household, a DC fan operational during summer (four months) and not in winter is taken into account. The system design is for maximum electrical load requirement. Total load calculated is shown in Table 5.

Hence, for the example household, a PV system which can meet the daily energy demand of 387 Wh/day will be designed.

Table 5. Total load requirement of example household

Unit	Number	Wattage (W)	Usage (hours/day)	Load (Wh)
CFL	2	11	5	110
CFL	1	9	3	27
TV	1	18	5	90
Fan	1	20	8	160
Total load (Wh/day)				**387**

Number of PV panels required

The number of PV panels required to meet the daily energy demand can be calculated by either using the wattage of the panel and the mean daily solar insolation in the region, or by first determining the array load and then the array size. The second method is the most frequently used one. As mentioned earlier (Chapter II), system losses occur owing to use of battery, charge controller, and inverter. The efficiency of different system components is given below.

Battery	80%
Charge controller	90%
Mismatch factor	0.85%

The average insolation during the least sunny days is 5.2 kWh/m^2/day in India. Using these values, one can determine the total array size or capacity of the system that will be required to meet the daily energy demand. Panels are available in certain rated capacities – 35, 50, 70 W$_p$. Accordingly, the number of panels that will be required to meet the total daily energy demand can be ascertained.

$$\text{Array load} = \frac{\text{Total daily load (Wh / day)}}{\text{Battery efficiency} \times \text{Charge regulator efficiency}}$$

$$\text{Array size} = \frac{\text{Array load}}{\text{Insolation} \times \text{Mismatch factor}}$$

Example. For the total daily load demand of 387 Wh (of the example household), the array load and the array size is as follows.

$$\text{Array load} = \frac{\text{Total daily load (Wh / day)}}{\text{Battery efficiency} \times \text{Charge regulator efficiency}}$$

$$\text{Array load} = \frac{387}{0.8 \times 0.9}$$

$$= 538 \text{ Wh / day}$$

$$\text{Array size} = \frac{\text{Array load}}{\text{Insolation} \times \text{Mismatch factor}}$$

$$\text{Array size} = \frac{538}{5.2 \times 0.85}$$

$$= 129 \text{ W}_p$$

Thus, panels which can deliver 129 W$_p$ are required. The options available are to select one of the following depending on cost and space available to install.

- Four panels of 35 W_p (140 W_p)
- Three panels of 50 W_p (150 W_p)
- Two panels of 70 W_p (140 W_p)

Installation of a PV panel

It is usual to position a PV panel or module facing the south in the northern hemisphere and north in the southern hemisphere. Ideally, to gain the maximum energy the PV module can be mounted on a tracker to face the sun continuously, as this may increase the output by up to 25%. As this is not practical in most cases, the best compromise for a fixed solar panel is to face it square to the sun at noon. If the module is inclined from the horizontal surface of the ground at a 'tilt angle' corresponding to the latitude of that location, then it will be square to the sun at noon at the equinoxes (21 March and 21 September). A steeper angle increases the output in winter while a shallower angle gives more output in summer. In practice, it is preferred that the panel should be fixed at an angle corresponding to the latitude of the place, to which it is necessary to either add or subtract another 10 degrees depending on the season. In winters 10 degrees is added to the latitude while in summers 10 degrees is subtracted so as to receive maximum solar insolation. In the equatorial and tropical regions, the tilt angle should be at least 10 degrees in order to ensure good run-off (of rain water) to keep the panels clean and also for better cooling. Table 6 gives the optimum tilt angle at different latitudes.

Table 6. PV panel tilt angle

Latitude (degree)	Optimum tilt angle (degree)
9	15
10–20	Latitude + 5
21–45	Latitude + 10
46–65	Latitude + 15
66–75	80

Determining the battery bank

Batteries are used only in such systems where the loads are used during non-sunshine hours or require items (like vaccines) to be stored. The battery rating is given in terms of Ah and hours rating. Therefore a 12 V, 40 Ah battery also has 10-hour rate discharge mentioned with it. This mean that a 12 V battery would have 480 Wh (12 V × 40 Ah) and the power can be drawn at the rate of 4.8 A over 10 hours.

Reserve day

Reserve day is a term used to indicate the minimum back-up energy that is required to be stored in the battery. Reserve day is determined according to the prevalent climatic conditions. In India, in the north-eastern states and the Himalayan belt (areas receiving very high rainfall), a back-up of three days is provided with the system. In the remaining parts, two days reserve is sufficient.

Battery bank and battery number

Battery sizing is one of the most critical factors of system sizing. It depends largely on the region where the system is being installed. In India, the following configurations of batteries are commonly used in the PV systems (Table 7).

While designing the battery capacity, it is important to know that the batteries cannot be fully discharged. As a safety measure, care is taken to see that the battery is not discharged beyond 50% of its capacity, as the battery cannot be charged completely once this state is reached and will always operate below its rated performance. In some calculations, this value is taken as 20%.

Table 7. Configuration of batteries commonly used in PV systems

Nominal voltage (V)	Ampere-hour (Ah)
12	7
12	40
12	70
12	100

$$\text{Battery capacity} = \frac{\text{Daily load (Wh)} \times \text{Reserve back-up}}{\text{Nominal voltage} \times \text{Maximum allowable discharge}}$$

Example. If the daily load is 387 Wh (example household), then the number of batteries required for a system with two days' reserve back-up will be:

Load = 387 Wh
Reserve days = 2
Maximum allowable discharge = 50%

$$\text{Battery capacity} = \frac{\text{Daily load} \times \text{Reserve days}}{\text{Nominal voltage} \times \text{Maximum allowable discharge}}$$

$$= \frac{387\ \text{Wh/day} \times 2\ \text{days}}{12 \times 0.6}$$

$$= \frac{774\ \text{Wh}}{6}$$

Battery capacity = 129 Ah

To determine the number of batteries, we can use the above formula and decide on the combination. Either four batteries of 40 Ah or two batteries of 70 Ah can be selected.

System design

The system design includes the number of panels, batteries, and the load points. Besides these, other components include charge controller, inverter, and mounting equipment. The system design for the example household would be as follows.

Panels : 4 × 35 W_p/ 3 × 50 Wp/ 2 × W_p
Battery : 4 × 40 Ah/ 2 × 70 Ah
Load : 2 × 11 W CFL
1 × 9 W CFL
1 × 18 W B&W TV
1 × 20 W DC fan (summer months)
Reserve back-up : 2 days

The number of panels will depend upon the place of installation and the available space over there. The same applies with the batteries. Another factor that will influence the number of panels and batteries is their market prices.

Designing a PV system without battery back-up

The most common application of this type of system is the solar water pump, used for supplying drinking water or for irrigation. The procedure for designing such systems involves ascertaining the daily water requirement which determines the load and the size of the PV array. It is important to note that since the requirement of water either for irrigation or for drinking water (water stored in a tank) is mainly during the period when adequate solar insolation is available, there is no need for an electrical storage device (battery).

Determining the total water head

This is the most important step in designing water pumping systems. Head (in metres) indicates the level from which the water has to be lifted or pumped. Both static head and dynamic head have to be calculated. Static head is the height over which the water has to be pumped and dynamic head is essentially a function of friction losses and the draw down. In the case of PV pumps for irrigation, the total water head is the sum of static head and dynamic head. In the case of pumps for drinking water supply, the total head is the sum of the total head (static and dynamic) and the height of the storage tank from the ground level.

Total water head = Static head + Dynamic head (PV irrigation pumps)
Total water head = Static head + Dynamic head + Height of storage tank (drinking water supply)

Example. If a PV pump for drinking water is to be installed in a village, then water is to be pumped from a height of 15 m. The water then has to be pumped to a storage tank which is at a height of 15 m. Dynamic head of the system is approximately 7 m (frictional losses of lifting water to the storage tank are included).

Total water head = Static head + Dynamic head + Height of storage tank
= 15 + 7 + 15 m = 37 m

Determining the water demand

Water demand is the basic minimum quantity of water that is required by a person. According to the Government of India standards, a minimum of 40 litres of water per person per day should be made available. The water demand is always calculated for the targeted year. The population of the village is projected for the design period. In case of PV pumps for agriculture-related activities, the daily water requirement in terms of cubic metre is taken into consideration.

Example. If the population of the village in 1998 is 500 (100 households), and the projected population for the year 2008 (the design period) is 625, then the daily water demand of the village in the year 2008 is to be calculated. In some calculations, the per capita increase in water requirement of a person is also included. In this calculation, we assume that the per capita water demand would remain constant at 40 litres per day.

Daily water demand = Population × per person daily water demand
= 625 × 40 = 25 000 litres/day
= 25 m^3/day (1 m^3 = 1000 litres)

Determining the system size

The system size in the case of drinking water supply would also include the number of days for which the water has to be stored. Generally, two to three days of water storage is accounted for in designing the system. However, the first step is to determine the total energy that is required to lift the water. Although there are no charge controllers and battery, certain conversion losses at the time of water pumping occur. This is normally in the range of 85%–90%. The average solar insolation in India is 5.2 kWh/m^2/day.

Energy required = Mass of water × Gravity × Total water head (in Joules or kJ)

Example. If the volume of water that has to be pumped for the design year of 2008 is 25 m³/day and the total head is 37 m, the inputs will be as follows.

Energy required = 25 × 9.8 × 37 × 0.28 = 2538 Wh/day (1 kJ = 0.28 Wh)

$$\text{Array load} = \frac{\text{Energy required}}{\text{System efficiency}}$$

$$= \frac{2538}{0.85} = 2986\ \text{Wh}$$

$$\text{Array size} = \frac{\text{Array load} \times \text{Reserve days}}{\text{Insolation} \times \text{Mismatch factor}}$$

$$\text{Array size} = \frac{2986 \times 2}{5.2 \times 0.85}$$

$$= 1351\ W_p \cong 1350\ W_p$$

System design

The PV system for the example village would require a PV array of 1350 W_p to lift water from a height of 15 m to an overhead tank (at a height of 15 m above ground) and use the water for distribution. Yet another important aspect of designing the system is to determine the type of the water pump (DC pump – submersible or surface mounted) which is available in the market. It is not possible to find a single pump which can lift 25 000 litres/day, and therefore, a combination of pumps has to be used. Irrespective of the number of pumps that will be required, the total wattage of panels would remain the same (1350 W_p). Depending upon the cost of panels, one can decide on which capacity panel has to be used. Most of the PV pumps in India have 70 W_p panels. Thus, in the village, if 70 W_p panels are used, then the number of PV panels required will be 20.

Conclusion

System designing depends upon the application and type of the loads to be operated. The load for domestic lighting systems is low, so smaller systems are used. For drinking water supply or PV irrigation, the demand and the consequent load are much higher. In such cases, the system design aims to optimize the available sunshine hours and hence configurations are of higher capacity (large systems). A similar process can be followed for system design in case of other applications such as PV refrigeration. As the demand for these is less, they are not available off the shelf and are usually designed by the manufacturers. The objective of the chapter was to provide an idea about system designing. Most of the manufacturers/system installers normally design the systems for the users. In the present scenario, pre-designed systems are also being installed.

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V

Costing of PV systems

The economic viability of a PV system is dependent upon the site and application. The cost of PV systems, in what is still a small and immature renewable energy market, can be highly variable, depending upon the location, the source and quality of systems and taxes or subsidies applicable. On pure market costs, PV systems are not economically viable. For instance, the cost of a PV array is more than the cost of a diesel generator (DG). The life of a DG set is 10 years, whereas the life of a PV panel is expected to be 20 years. Table 1 gives the expected life of different PV components.

Discounted life-cycle-cost (LCC) analysis method is used to explain the economic viability of PV systems when compared to a DG. The price of a PV panel fluctuates, largely due to demand for silicon in the software industry. It also varies from manufacturer to manufacturer. In 1991/92, the price of a panel was Rs 225/W_p, which gradually came down to Rs 165/W_p in 1995/96. However, in the past two years, the price of panels has increased considerably. Figure 1 gives the variation in the prices (per W_p) of a PV panel.

By LCC analysis method, PV systems are much more economically viable than alternative sources such as grid and diesel, if the loads are smaller. This is because in the case of smaller loads, the system can be designed accordingly to meet the demand. Whereas, in the case of DG sets, one has to buy a minimum practical size of generator, which may still be oversized for rural applications.

Table 1. Typical life expectancy of PV components

Components	Years
PV module	20
Regulator	15
Inverter	5–15
Batteries	1–3 (automotive) 3–5 (solar)
Wiring	10

Source. IT publications (1997)

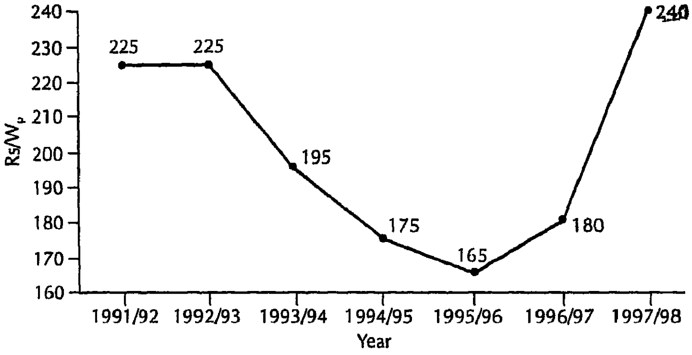

Figure 1. Trend in PV prices

The cost of PV systems would decrease further if there is an increase in the volume of production. The production of the modules and the panels has been increasing steadily to meet the existing demand. In India, the installed capacity of PV production up to 1996/97 was 35 MW, whereas the cumulative installation for different applications was 25 MW (up to 1997). The annual production of solar PV (SPV) cells has more than doubled in the past four years (Figure 2). The production of PV modules has increased from 2–3 MW$_p$ in 1992/93 to 7–8 MW$_p$ in 1996/97 (Figure 3).

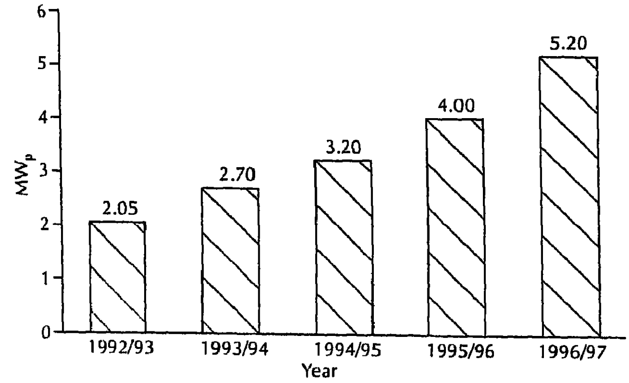

Figure 2. Annual production growth of PV cells
Source. MNES (1997)

Cost of PV systems

It is important to understand that the customers do not buy PV systems based on LCC analysis. Factors that influence the purchase of PV systems have been listed below.

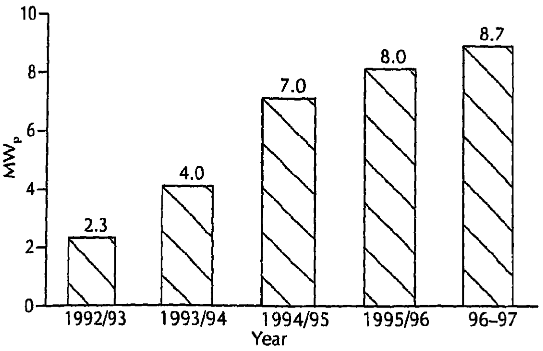

Figure 3. Annual production growth of PV modules
Source. MNES (1998)

- Upfront cost
- Ease of operation and maintenance
- Reliability and confidence in technology
- Availability of spare parts and repair and maintenance facilities

The high upfront cost of PV systems is one of the major constraints in its large-scale dissemination. The market price of the systems varies from manufacturer to manufacturer. Manufacturers like the Bharat Heavy Electricals Ltd, Tata-BP Solar, Rajasthan Electronics and Instruments Ltd, Renewable Energy Systems, and Central Electronics Limited, market complete systems. In addition to these, there are system integrators in the market, who buy components (like solar panel and batteries) of PV systems from these manufacturers and assemble and market them. Table 2 provides the market prices of most systems according to 1997/98 prices. These market costs are given in range, as the cost of systems provided by the system integrators are normally less, when compared to those directly supplied by the manufacturers.

Subsidies and soft loans

The purchasing decisions of the consumer gets highly influenced by the tax or subsidies which the government provides on these systems. The Ministry of Non-conventional Energy Sources (MNES), Government of India, provides cost subsidy on the system cost. Depending upon the application, the subsidy varies. In addition to this, the Indian Renewable Energy Development Agency (IREDA) provides soft loans (low interest loans) to the users of the system. Except in the case of PV pumps, if the systems qualify for subsidy under the MNES programme, then soft loans from IREDA are not available. Tables 3–5 present the financial and fiscal incentives available for PV systems.

Table 2. Market prices of SPV systems

System	System size	Market prices (Rs)
Solar lantern	10 W_p 7 W/5 W compact fluorescent lamp (CFL) for four hours	4000–5000
PV domestic lighting system	20 W_p, 40 Ah battery, 29 W CFL for two hours	12000–15000
	35 W_p, 90 Ah battery, 211 W CFL for three to four hours	12000–18000
	50 W_p, 90 Ah battery, 2–9 W CFL for four hours, 120 W black & white TV for four hours	20000–22000
PV pump: agriculture	900 W_p, surface mounted pump for water lifting up to 30 feet	250000 Post subsidy and IREDA-World Bank Programme: Rs 88000
Solar sprayer	5 W_p including the sprayer	4000
Solar street light	Six hours operation 35 W_p, one 11 W CFL	27000
	Six hours operation 70 W_p, two 11 W CFL	37600
	Dusk to dawn (12 hours) 70 W_p, one 11 W CFL	36000
	Dusk to dawn (12 hours) 100 W_p, two 11 W CFL	52000
Solar vaccine refrigerator	50 litre capacity, World Health Organization specifications	180000

Table 3. Financial incentives provided by the MNES (1998)

System	Subsidy
Domestic lighting system	50% of ex-works cost, subject to a maximum of Rs 6000/- per system
Street lighting system	Maximum of Rs 12 000/-
Solar lanterns	Rs 1500/- per solar lantern
Small SPV power plants	Maximum of Rs 200 000/- per kW
SPV pumps	(1) Subsidy of Rs 125 W_p subject to a maximum of Rs 200 000/- and (2) Loan of Rs 50 000/- to 250 000/- depending on the size of the SPV array and the capacity of the pump Interest: 2.5% (5% to the user) per annum Repayment period: 10 years

Source. MNES (1998)

Table 4. Financial incentives provided by the IREDA (1998)

(IREDA loan for SPV systems under the World Bank programme)

SPV domestic and stand-alone systems (IREDA loan: 85% of the project cost)	
Interest for rural applications	2.5%
Interest for other than rural applications	5.0%
Promoter's contribution	15.0%
Repayment period	10 years
SPV water pumping systems (IREDA loan: 85% of the project cost)	
Interest	2.5%
Promoter's contribution	15.0%
Repayment period	10 years
Small SPV power plants	
Interest for main grid interactive/inter-tied systems for export of power to grid	5.0%
Interest for main grid interactive systems for captive consumption and localized grid interactive systems	2.5%
Promoter's contribution	15%
Repayment period	10 years

Source. IREDA (1998)

Table 5. Fiscal incentives provided by MNES (1997)

Fiscal incentive	Excise duty/ customs duty benefits
Silicon in all forms, that is, polycrystalline silicon or silicon ingots, for manufacturing undiffused silicon wafers	10%
Undiffused silicon wafer for manufacturing solar cells or solar cell modules	10%
Solar cells and modules and PV systems, for manufacturing PV applications	30%
Silver powder suspension	Nil
Silicon resin and silicon rubber	Nil
Accelerated depreciation on specified non-conventional renewable energy devices/systems in the first year of the installation of projects	100%
Tax holiday on renewable energy power projects	Five years

Source. MNES (1997)

Costing of PV systems

Photovoltaic (PV) system costing is done using the per watt peak cost of the panel. The thumb rule is that the total cost of the PV panel is 50% of the system cost. In the Balance of System (BoS), the battery cost is nearly 15% and equivalent share is of the cost of the charge controllers, inverters, and other electrical equipment. The balance 20% are the indirect costs, which mainly includes taxes. A few studies have indicated that the share of the panel is 52% of the total cost, while one of the studies states that it is 44%. Once the system designing has been completed, one can calculate the approximate cost of the system.

Example. Based on the system design with back-up as mentioned in the previous chapter, the expected expenditure on the system can be calculated.

The system design for the household was a PV system with total power requirement of 129 W_p. If the per watt peak cost of the panel in 1997/98 is considered, then the approximate cost of the PV system can be worked out. In 1997/98, the cost of the PV system was Rs 240/W_p. Therefore, the cost of the panels is approximately Rs 31 000/-. If the thumb rule of 50% is taken into consideration, then the system cost becomes Rs 62 000/-.

Conclusion

Given the very high capital cost of a PV system, it is essential that adequate credit facilities are available. One school of thought is of the opinion that if the government continues with the subsidy programme, then it will not allow private market to develop; while another school of thought proposes that it is still not the appropriate time to remove subsidies from PV systems. The technology has still not reached the stage where it can be marketed or promoted on full-scale commercial terms. What is, therefore, required is to have a right balance of subsidy and low interest loan to promote the systems on a wider scale. With the introduction of thin film cells as panels, the cost of the panels is likely to go down, but so would the conversion efficiency. The price of crystalline silicon cells is likely to reduce, but it is expected to remain in the range of Rs 180/W_p to Rs 225/W_p for a few more years. In order to bring down the cost of PV systems, a market of several million solar lighting systems is required, which is not possible to achieve in the near future, given the poor rural infrastructure that exists.

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VI

Maintenance of PV systems

Lack of maintenance of photovoltaic (PV) systems is identified as one of the most critical factors in the wider acceptance of the technology. A majority of the systems in the field fails owing to lack of proper repair and maintenance facilities. All PV systems require maintenance on a regular basis. Maintenance ensures that systems would operate effectively and efficiently, and in many cases would also prevent occurrence of problems in future.

Maintenance of PV systems requires minimal time, involving a simple procedure. Owners can maintain the systems themselves. Nevertheless, it is advised that major maintenance is undertaken only by trained technicians, who are familiar with PV systems, other associated components, and proper safety procedures. The basic information on the maintenance procedures, *do's* and *don'ts* of PV systems, and troubleshooting tips are provided in subsequent sections.

Maintenance procedures

Maintenance of a PV system involves the examination of several component categories. Each component should be inspected in an orderly manner. Since some PV systems (large capacity systems) operate at high voltages and currents, proper safety procedures must be followed. The use of appropriate tools and materials is required for proper maintenance. The general procedure for maintenance of the systems is (1) inspection of the systems at least twice a year and (2) developing and maintaining inspection forms and records.

PV panel

The PV panel is one of the most vital components of the system as it is the source of electricity generation. The life of the panels is approximately 20 years, and is generally problem-free. The most commonly occurring problem in the panels is that sufficient electricity is not generated. This may be either due to accumulation of dirt, shading on the panels, electrical problems, incorrect orientation, or tilt angle. The maintenance procedure involves the following.

- Check for delamination, discolouration, cracked or broken cells, excessive dirt, or bird droppings

- Check for shadows and shading in early mornings and late afternoons
- Ensure that there is no excessive vegetation growth around the panel
- Ensure that modules are well attached to the frame, and check the frame for corrosion
- Inspect junction box seals for cracks and moisture
- Make seasonal tilt adjustments as required
- Measure current and voltage of individual panels/array

At the time of installing the PV system, it must be ensured that there is no shading from the panels (if more than one panel is used) on each other. Some of the common *do's* and *don'ts* are mentioned below.

Do's

- Clean the panel surface regularly with clean, dry/wet cloth
- Check all the cable and wiring connections for their firmness
- Check that there is no corrosion in the panels and there is no seepage of rain water

Don'ts

- Do not use detergent for cleaning the panel
- Do not use sharp-edged materials to remove bird dropping
- Do not touch the surface of the panel with oily or greasy hands
- Do not attempt to open the circuits and the wiring

It is essential to remember that there is very little that can go wrong with the panels, but the solar cells in the panel are so fragile that once dismantled it is almost like installing a new panel. So enough care must be taken to maintain the panel.

Batteries

Batteries are the energy-storing devices. One of the main problems highlighted in evaluation studies related to systems was the failure of batteries (TERI 1998). Often it is assumed (by the users) that the battery has sufficient storage and, therefore, loads can be operated for longer duration. The manufacturers and the system installers often design a system in which the battery would reach a discharge stage if the current withdrawn from it is more than 50%. The following procedure should be followed for maintenance of batteries.

- Inspect battery terminals for corrosion and loose cables
- Check battery surface for electrolyte leakage
- Ensure that batteries are not in direct contact with the floor
- Check battery enclosure box for proper ventilation
- Check the level of electrolyte and distilled water in the batteries; top-up the battery if the level is below the specified mark
- Check the specific gravity of the cells

The battery must be placed in an enclosed box. It should be kept at a place away from direct human contact. Some of the common *do's* and *don'ts* are given below.

Do's

- Battery must be charged daily
- Clean the battery top with a cloth/brush with baking soda and water solution

Don'ts

- Do not keep any inflammable objects near the battery
- Do not keep the battery exposed; always keep it in a sealed box which has proper ventilation
- Do not add additional load to the battery as it will reduce its life

It is essential to remember that even at very low voltage, a large battery bank can release high current. It is always safe to have protective gears at the time of battery maintenance, as there is always a possibility of explosion.

Electronic components

Apart from system failure due to battery, the other common reason cited is the problem with the electronics. A study by Maithel *et al.* (1997) indicated that 80% of the solar lanterns failed due to problems in electronic components. It is essential, therefore, to regularly maintain the electronic components.

- Verify voltage set points of charge controller with regard to battery specifications and system requirements
- Check connections for corrosion and loose wires
- Listen for unusual noises from charge controller such as relay chatter
- Ensure that charge controller is in a sheltered, clean, and well-ventilated environment

Wiring

- Check wiring connections for corrosion and looseness
- Check wire insulation for degradation
- Ensure that all metal equipment cases and frames in the system are well grounded (all the way to the grounding object)
- Check the operation of all light emitting diodes (LEDs)
- Check circuit breakers and fuses

These are some of the common maintenance procedures that can ensure long life of the systems. Some of the problems in the systems can be easily detected and corrected. Tables 1–6 on troubleshooting outline actions that need to be initiated if some of the problems arise.

Table 1. Troubleshooting for PV panels

Problem	Cause	Result	Action
No current from array	Switches, fuses, or circuit breakers open, blown, or tripped; or wiring broken or corroded	No current can flow from array	Close switches, replace fuses, reset circuit breakers, repair or replace damaged wiring
Array current low	Some modules shaded	—	Remove source of shading
	Some modules damaged or defective	—	Replace the module
	Full sun not available	—	Remove source of shading/check the orientation of panel
	Modules dirty	—	Clean the module surface
	Array tilt or orientation incorrect	—	Correct the tilt angle

Source. NFEC (1989)

Table 2. Troubleshooting for batteries

Problem	Cause	Result	Action
No apparent battery defect but low battery charging	Load too large, switched on for too long, or inadequate sun	Battery is always at a low state of charge	Reduce load size or increase system size
	Batteries too cold	A higher voltage is required to reach full charge	Insulate battery enclosure
Low electrolyte level	Overcharging	Loss of battery capacity	Add distilled water, unless batteries are damaged beyond repair
Voltage loss overnight even when no loads are ON	Faulty blocking diode	Reverse current flow at night, discharging batteries	Replace diode
Voltage not increasing even when no loads are ON and the system is charging	Faulty charge controller	No power from array going into batteries	Repair or replace charge controller
	Loose, corroded, or broken wiring	Less power from array going into batteries	Repair or replace damaged wire
	Shaded modules, broken cell, or disoriented panels	Array output reduced	Remove source of shading, replace module, or correct module orientation
	Wiring too long or undersized	Voltage reduced	Check wire size
No apparent battery defect	Load too large, ON too long, or inadequate sun	Battery is always at a low state of charge	Reduce size of load or increase size of system
High water loss	Overcharging	Heat damage to plates and separators	Replace battery, repair or replace charge controller

Source. NFEC (1989)

Table 3. Troubleshooting for charge controllers

Problem	Cause	Result	Action
Controller not charging batteries	Poor connection at battery terminal	Charge controller finds batteries cooler than their actual temperature	Repair, readjust, or replace charge controller
Battery voltage loss overnight even when no load is ON	Faulty blocking diode, no diode or faulty charge controller	Reverse current flow at night, discharging batteries	Replace or add diode, or repair or replace series relay charge controller
	Old or faulty batteries	Batteries self discharging	Replace batteries
Fuse to array blows	Array short-circuited with batteries still connected	Too much current through charge controller	Disconnect batteries when testing array's short-circuit current
	Current output of array too high for charge controller	Too much current through charge controller	Replace charge controller with a higher rating one
Fuse to load blows	Short circuit in load	Unlimited current	Repair short circuit or reduce load size
	Current draw of load too high for charge controller	Too much current through charge controller	Reduce load size or increase charge controller size
	Surge current draw of load too high for charge controller	Too much current through charge controller	Reduce load size or increase charge controller size

Source. NFEC (1989)

Table 4. Troubleshooting for inverters

Problem	Cause	Result	Action
No output from inverter	Switch, fuse, or circuit breaker open, blown, or tripped, or wiring broken or corroded	No power can move through inverter	Close switch, replace or reset fuse or circuit breaker, or repair wiring or connections
	Low voltage disconnect on inverter or charge controller circuit is open	No power available to inverter	Allow batteries to recharge
	High battery voltage	Inverter does not start	Connect load to batteries and operate it long enough to bring down battery voltage

Source. NFEC (1989)

Table 5. Troubleshooting for system wiring, switches, and fuses

Problem	Cause	Result	Action
Load does not operate at all	Switches in the system are turned OFF or are in the wrong position	PV electricity cannot be supplied to loads or batteries	Put all switches in correct position
Load operates poorly or not at all	There is a high voltage drop in the system. Check for under- or over-sized wiring, over-sized loads, or a defective diode	Inadequate voltage to charge batteries or operate loads	Increase wire size, reduce load size
	Wiring or connections are loose, broken, burned, or corroded	—	Repair or replace damaged wiring or connections
	Wiring or connections are short-circuited or have a ground fault	—	Repair short circuit or ground faults

Source. NFEC (1989)

Table 6. Troubleshooting for loads

Problem	Cause	Result	Action
Load does not operate at all	Load is too large for the system or inadequate sunshine	Shortened battery life, possible damage to loads	Reduce load size or increase array or battery size
	The load is in poor condition. Check for short circuits in load, a broken load, or an open circuit in the load	Shortened battery life possible, further damage to loads.	Repair or replace load, check load, follow up with manufacturer/ system installer for service information

Source. NFEC (1989)

Conclusion

The objective of providing information on maintenance of the systems and general troubleshooting was to give an overview of what all can probably go wrong with a PV system. Most of these problems are simple and can be solved by the user itself, but it is always advised that a trained technician looks into these problems.

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VII

Overview of solar photovoltaic programme in India

Introduction

The promotion of photovoltaic (PV) technology in India has been mainly guided by two approaches. The first approach has been the government strategy for promotion of the technology, which is basically subsidy driven. The other is a market-driven approach attempting to commercialize the technology for various applications.

The PV technology programme in India dates back to the late 1970s. However, as a full-fledged national programme, it was initiated by the MNES in the late 1980s. This was essentially a demonstration programme for PV technology, with focus on utilizing the solar energy potential in the country for domestic lighting, pumping, and refrigeration. A central subsidy was provided as a means to popularize solar photovoltaic (SPV) systems among the rural consumers.

The PV programme received a major boost in 1992 when the Indian Renewable Energy Development Agency (IREDA)[1] established a revolving fund offering affordable credit for the purchase of PV systems. The fund is a World Bank assisted PV market development programme being implemented by IREDA.

Besides state governments and other government agencies such as IREDA, some local organizations have evolved innovative approaches for the promotion of technology in the rural areas. Some examples are the Solar Electric Lighting Company's (SELCO's) approach to commercialization of PV technology in the rural areas of Karnataka and other non-governmental organizations (NGOs) such as the Ram Krishna Mission, West Bengal.

Information on the subsidies (Table 1) and other benefits offered by the MNES under the Demonstration and Utilization Programme and procedures for availing these benefits is provided in the following sections. In addition to the

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[1] The IREDA was established in March 1987 under the MNES, Government of India. Its major objective is to extend financial support to manufacturers of new and renewable sources of energy systems and devices by establishing a revolving fund.

Table 1. Subsidies under the MNES programme

System	Subsidy
Solar lantern	Rs 1500/-
Domestic lighting system	50% of ex-works cost or Rs 6000/-, whichever is less
PV street light	Rs 12 000/-
Water pumping ·	Rs 125/W_p, subject to maximum of Rs 200 000/-

Source. MNES (1998)

MNES subsidy, several state governments provide additional subsidies to the users. In the following sections, the IREDA programme objectives, eligibility criteria, the nature of assistance extended to participants, financial norms, and products eligible for financing are outlined. The innovative approaches of entrepreneurs and NGOs such as SELCO and the Ram Krishna Mission are also presented as case studies.

Demonstration and utilization programme of the MNES

Under this programme, the MNES provides subsidy to the extent of 50% of ex-work cost of the PV systems, subject to certain upper limits. The subsidy for solar lanterns is, however, fixed at Rs 1500/-. In addition, service charges are paid to the implementing organizations at the rate of Rs 100/- per solar lantern and Rs 200/- per home lighting system (MNES 1997). From 1996/97, all categories of individual beneficiaries and non-profit institutions/organizations have become eligible for availing central subsidy on all PV systems covered by the MNES programme. The state implementing agencies have been allowed direct marketing of PV systems by the manufacturers under the subsidy programme. Also, the sale of solar lanterns and other SPV systems from MNES-supported showrooms (called ADITYA) operated by certain state nodal agencies, manufacturers associations, and NGOs has been initiated under the subsidy programme. Figure 1 gives the distribution of PV systems till March 1997. Rural telecommunication projects have the maximum share (41%) of PV installation, with Railways constituting the most of others (22.5%). PV systems in the rural areas for different applications put together have a share of 36.5%.

Solar water pumping programme

The Ministry is also implementing a programme on the dissemination of PV water pumping systems for agriculture and related use. The PV water pumping programme aims at the gradual introduction of PV pumps. It also covers development of marketing infrastructure for pumping systems and obtaining

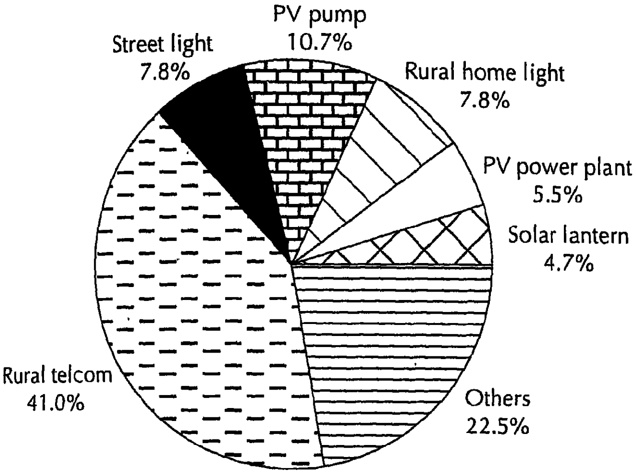


Figure 1. Performance of MNES programmes
Source. MNES (1997)

direct feedback on the performance and utilization of SPV pumps for meeting the specific needs of the users in different agroclimatic conditions for different categories of consumers for different end uses. The IREDA has been entrusted with the responsibility of implementing the programme. The programme envisages a subsidy and a soft loan arrangement. The programme covers water-pumping systems in the range of 200–2250 W_p of PV array capacity. The programme is open to all categories of consumers. Till February 1998, 2409 PV pumps were installed for different categories of users.

At present, the subsidy on water pumping systems is Rs 125/W_p of the PV array used with the pumping system, subject to a maximum of Rs 200 000/- per system. The IREDA line of credit (interest rate, promoter's contribution, and repayment period) for different applications has been given in the previous chapter.

The MNES also supports training programmes on operation and maintenance and water management aspects of the PV pumping systems. These cover the actual users, local technicians/mechanics, and rural youth.

SPV power programme

In November 1995, the MNES launched a scheme to augment and supplement grid power by installing PV power projects in the range of 25–100 kW for two niche applications.

- Rooftop systems on public buildings to demonstrate peak load shaving applications in a major urban centre

- Distributed grid transmission and distribution support systems in remote rural areas at tail-end grid sections.

Under the scheme, a subsidy of two-thirds of the total project cost, subject to a maximum of Rs 20 million per 100 kW capacity, is provided to state electricity boards (SEBs), state nodal agencies, and private utilities. During the financial year 1997/98, 6 kW_p capacity of PV power plants has been installed.

SPV market development programme

The PV dissemination programme in India received impetus in 1993, when the SPV market development programme was launched. This is a World Bank assisted programme implemented by IREDA. The period of operation of the programme is from 1993 to 1998, which has since been extended to September 1999. The objectives of the programme are:

- to encourage the establishment of sustainable product supply, delivery, after-sales service, and financing mechanisms to support PV products on a commercial scale
- to generate impetus and create a favourable environment for the PV industry to establish growing and profitable business enterprises
- to foster deployment of commercial PV systems for lighting, water supply, and other applications.

Under the World Bank line of credit, IREDA received revolving credit from three sources – International Development Agency (US $30 million), Global Environment Facility (GEF) (US $10 million), and Swiss Agency for Development and Cooperation (US $2 million). IREDA has sanctioned 1876 kW_p of project till June 1998, amounting to Rs 91.9 million.

The revolving fund from IREDA provides direct lending, or aggregated procurement, on behalf of large volume buyers of PV systems. The fund also lends to financing and leasing companies, who, in turn, service the lower volume consumers such as individuals or village communities (Table 2). The eligible products for financing include:

- lighting systems for domestic and commercial establishments – solar lanterns, lighting and other low power applications, street or security lighting;
- community service systems (schools, community centres, health centres, etc.);
- village power systems (battery-charging stations, DC systems, AC systems, AC PV-diesel hybrid systems);
- water-pumping applications;
- water purification systems (filtration plants);
- crop sprayers;

Table 2. Eligibility criteria for the IREDA programme

Category	Eligibility criteria
End users	All interested parties, except government departments and SEBs. No accumulated losses (without taking into account revaluation of assets, if any) Profitable working in the last year of operation Legally eligible to borrow funds
Equipment suppliers	Local manufacturers of SPV systems and components of their authorized agents/franchises Authorized local agents of experienced foreign suppliers
Financial intermediaries	Only the organizations allowed to borrow funds under their Articles of Association and conduct the business as per MOA Minimum three years of operation, no accumulative losses, profit making and minimum turnover of Rs 5 million in the last year of operation is essential in the case of an existing company Companies which have three years of operation, will be considered on the basis of strength, and support of the parent company should be in operation for minimum three years, no accumulated losses profit making and minimum turnover of Rs 30 million Shall comply with a Non Banking Financing Companies at the rate of regulation as defined by the Reserve Bank of India No legal litigation Loan recovery track record should be at least 80%.

Source. IREDA (1998)

- vaccine refrigeration; and
- power generation systems (stand-alone or grid-connected).

There has been steady increase in the projects sanctioned by IREDA. Initial problems were mainly related to the operational procedures involved in disbursement of loans. Figure 2 gives the trend in the installation of PV systems under World bank line of credit (till June 1998).

Figures 3 and 4 illustrate the system-wise installations in terms of installed capacity and loan amount disbursed (till June 1998). Majority of the loan disbursed is for solar lantern projects (33%), followed by home lighting systems (27%).

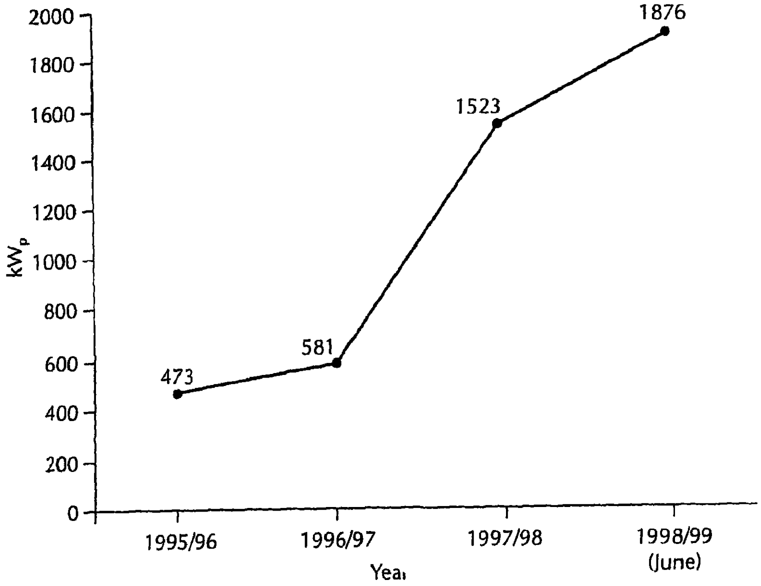


Figure 2. Trends in installation of PV systems
Source. IREDA (1998)

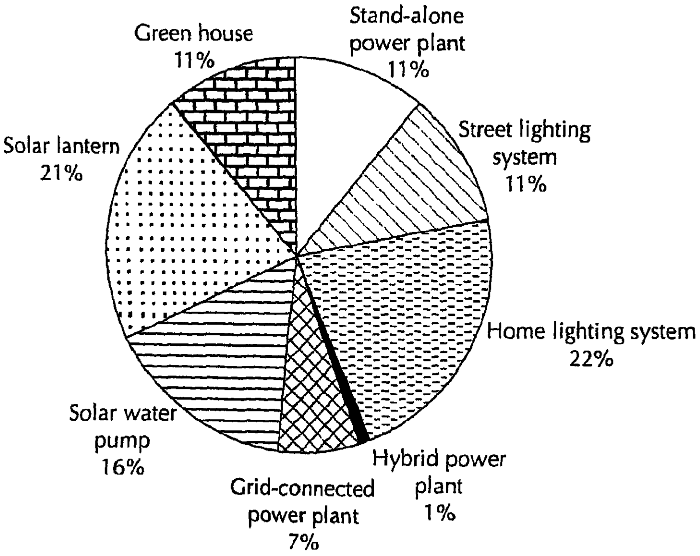


Figure 3. Status of PV projects - system-wise capacity (kW$_p$)
Source. IREDA (1998)

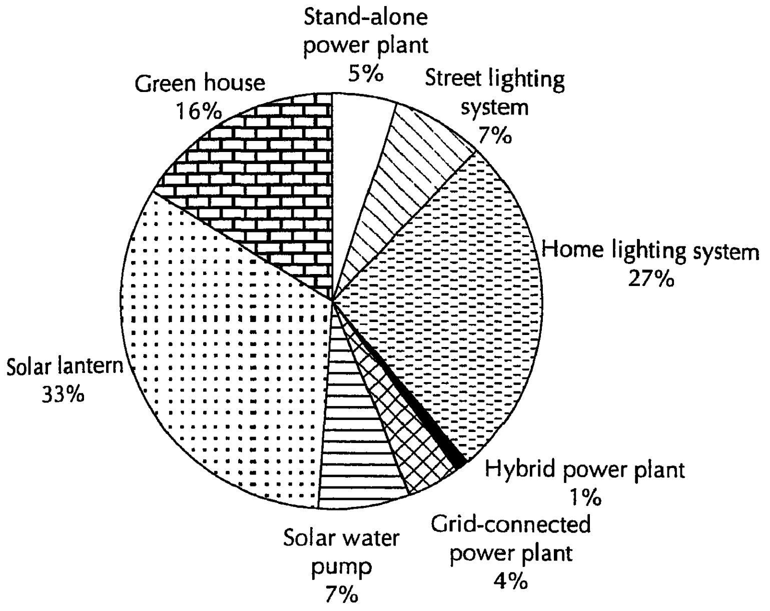


Figure 4. System-wise status of loan disbursement
Source. IREDA (1998)

Market development approaches

In the last few years, there have been several attempts to promote PV systems on full-scale commercial terms. Studies have indicated that the most crucial aspects for promoting these systems in the rural areas are infrastructure for repair and maintenance, and credit facilities. However, efforts made to establish such infrastructure, so far have had limited success.

A pioneering effort has been made by SELCO in southern India. It has established a service network by training the local entrepreneurs in installation, repair, and maintenance of PV systems. It has also created infrastructure for credit to potential consumers. Yet another approach has been in the Sundarbans area of West Bengal, where the Ram Krishna Mission has initiated the promotion of PV domestic lighting systems under the MNES programme. It has also created an infrastructure for repair and maintenance. Similar attempts have also been made by the Social Work Research Centre, an NGO, which evolved the concept of 'barefoot engineers', and trained local youth to provide back-up facilities.

SELCO's marketing models

SELCO India is a solar energy services company based in Mangalore which has established a process of distribution of PV systems by commercial channels as a profitable business. The main objectives of the company are (1) to provide electricity to the rural population and (2) to integrate PV into the main stream of the local culture.

SELCO essentially assembles and markets PV systems to rural households. It started its ground-level activities in the villages of Karnataka in April 1995, with a small amount of seed capital from the Rockefeller Foundation channelled through a US-based non-profit organization called Solar Electric Light Fund (SELF) Inc.

Till now, SELCO has sold and installed more than 700 solar home systems (SHS) and several PV pumping systems. It is the only solar energy services company that has been able to generate profits in the second year of its operation.

In addition to its headquarters in Mangalore, SELCO has six branches in other parts of Karnataka. All branches of SELCO maintain a staff of local technicians and collection agents in the selected villages. Each branch has a branch manager and four technicians. The technicians work for SELCO on an income-cum-commission basis with an incentive to sell more systems. Technicians double as salesmen also. Commission depends on whether it is a direct sale or a sale on a loan basis. The aim is to provide quick after-sales services to customers. It also facilitates monthly collection of loans.

The regional branches of SELCO focus on providing stand-alone systems and service in rural areas for lighting and water pumping. This strategy of SELCO has helped the company to establish beneficial relationships with nationalized banks, *grameen* banks, NGOs, IREDA, and international investing agencies for the promotion of PV systems.

SELCO's marketing models

SELCO has created different marketing mechanisms to suit the various categories of its customers (Figure 5). These mechanisms can be classified into four types.

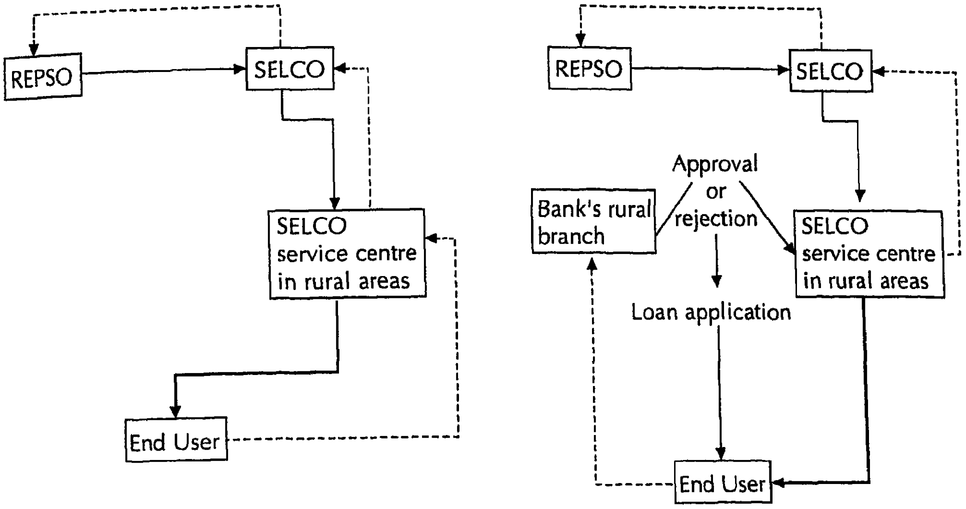
- Cash sale (direct sale to customers)
- Sale through nationalized/*grameen* bank (loan to customers)
- Sale through IREDA (system on lease-to-own basis)
- Sale through local institutions (marketing of systems through local institutions, namely, co-operatives, farmer societies, NGOs, etc.)

Lessons from SELCO experience

- Ready financing is available to the villagers through installment credit schemes.
- SELCO does not have the additional burden of collection of loan payments.
- Expansion of service area and customer base.
- Continuous availability of service.

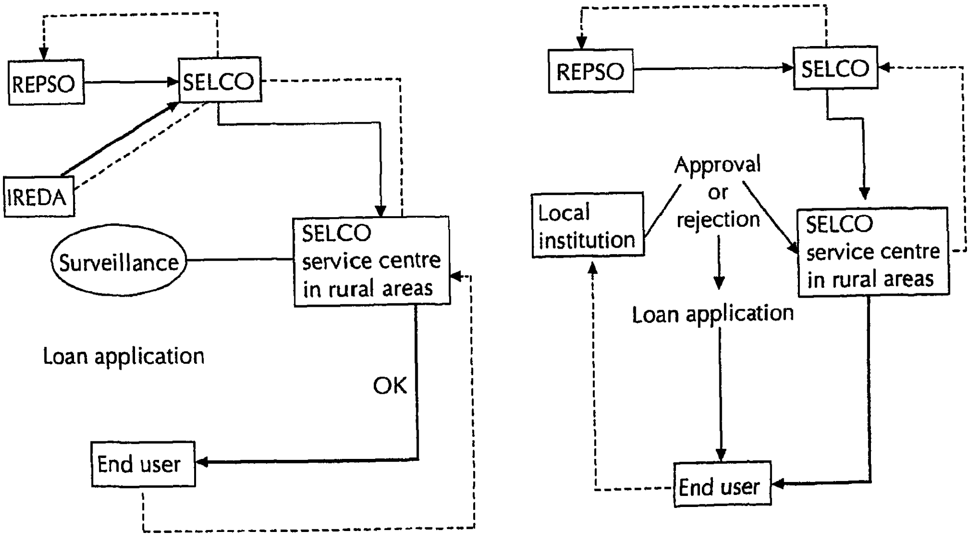
NGO approach: Ram Krishna Mission

The strategy adopted by the Ram Krishna Mission for the promotion of PV technology in rural areas is another novel experience. The *Lok Shiksha Parishad* of



a) Cash sale model

b) Sale through Banks



c) Sale through IREDA

d) Sale through local institutions

—— Flow of funds ------ Reflow of funds —— Flow of hardware and training

Figure 5. Marketing models of SELCO
Source. Naidu, Arora (1997)

the Ram Krishna Mission has a separate unit, which works on solar energy. The Solar Energy Unit (SEU) looks after the installation, repair, and maintenance of PV systems. It also manages the ADITYA shop, which is supported by the MNES and the West Bengal Renewable Energy Development Agency. It has installed more than 750 PV domestic lighting systems in the areas of Sundarbans, Midnapore, and parts of 24 Parganas(s) district. It is working on an MNES-supported project in which they are promoting the systems with the help of the affiliate cluster organizations at the block levels and the village youth clubs.

Infrastructure for PV promotion

At the SEU, there is a team of technicians and trained staff, which is responsible for the installation of the systems at different sites. It also orients the visitors to the ADITYA shop about the applications of the different systems and how these can be purchased. The Ram Krishna Mission implements the projects through the affiliate block level cluster organizations. However, only a few of these are involved in the installation of the PV systems. All these organizations have a team of skilled technicians, which assists the SEU team in installing the systems and also provides technical support to the village youth clubs. The village youth clubs are involved in the implementation of the projects.

Maintenance and repairs

The SEU looks after the major repair and maintenance of the systems. In most village youth clubs, trained technicians have been appointed to undertake minor repairs and maintenance. If the faults in the systems cannot be repaired by the village technician, they are taken to block-level organizations. Most of the faults in the systems can be repaired in block-level organizations. If the system cannot be repaired at the block level, then it is taken to the SEU.

Dissemination

Village youth clubs, block-level organizations, and the SEU are the dissemination centres. Potential buyers approach these centres and apply for the systems. In case the buyer needs credit, the block-level organization assist him/her in getting a loan from the commercial/local area banks. A few systems have been sold through this process and the interest rate charged by the bank is 12.5%. Village youth clubs and block-level organizations also conduct awareness programmes for the villagers and demonstrate the systems during *kisan / krishi melas* (agricultural fares).

Reasons for success

SPV programme of Ram Krishna Mission has achieved enormous success in two years. This has been possible primarily because of the following two reasons.

- Strong infrastructure for dissemination, repair, and maintenance
- Credibility of the organization

Future directions

Photovoltaic systems are already considered as one of the best options for rural infrastructure projects in unelectrified areas. However, PV systems at present require a large capital investment and this restricts their purchase by individual households. It is expected that the cost of PV modules will come down significantly, and this will happen with expansion of the market. One of the programmes that is currently under the planning stage is Photovoltaic Market Transformation Initiative (PV MTI). PV MTI is an International Finance Corporation and GEF-promoted project, which aims to accelerate the sustainable commercialization and financial viability of PV-based solar energy services. PV MTI funds for India is US $15 million, and the programme envisages an investment of US $45 million from Indian organizations. The project aims to strengthen the rural infrastructure like repair and maintenance facilities and develop financial models for easy availability of credit in the rural areas. These projects will be in operation from July 1999.

Conclusion

Several attempts have been made so far to increase the market share of the PV systems. Though, not all have been successful, most of the market promotion approaches have been successful in their respective geographical locations. Attempts to replicate those have not been successful and are also not likely to be successful. They key aspect to the market promotion of PV systems today is to create infrastructure for effective after-sales service. Approaches of the Ram Krishna Mission and SELCO have been successful largely because they addressed the problem of repair and maintenance and provided credit facilities. Another key aspect to the promotion of PV systems in rural areas is the availability of credit. If these two aspects of market development are taken care of, then there is a vast market of PV systems. And, it is in this context that programmes like PV MTI assume significance, as it provides opportunity to create and formalize these infrastructure in the rural areas.

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Naidu B S K, Arora R. 1997. Solarizing Rural India: a case study. New Delhi: R newable Energy Project Support Office - India, Winrock International.

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Glossary

Alternating current (AC) Electric current that reverses direction at frequent intervals, usually many times a second.

Amorphous Pertaining to a solid which is non-crystalline, having neither definite form nor structure.

Balance of System (BoS) Parts of a PV system other than the PV array. It includes batteries, charge controllers, electronic components, and mounting structure.

Battery A storage device in which the electricity generated from the solar panel is stored.

Blocking diode An electronic component, which prevents the discharge of batteries through a PV panel.

Charge controller An electronic component, which controls the rate of charging of the battery and protects the battery from over-charging or deep-discharging.

Conversion efficiency (solar cell) The ratio of electrical energy produced by a solar cell (under full sun conditions) to the energy from sunlight incident upon the solar cell.

Design month For the purpose of sizing an SPV system, it is necessary to choose the 'worst month(s)' [during which the solar radiation is not at its full; monsoon months or winter months] for which the system must meet the load requirements. This is termed as the design month.

Direct radiation Solar radiation transmitted directly through the atmosphere.

Direct current (DC) Electric current that flows in one direction only.

Diffuse radiation Solar radiation scattered by the atmosphere.

Global irradiance The sum of diffuse and direct solar irradiance. The total irradiation (sunlight intensity) falling on a surface.

Inverters Electronic components which convert the DC to AC, to operate AC loads, or vice-versa.

Kilowatt- hour 1000 Watt hours of energy

Kilowatt peak (kW_p) Power output of a PV module under standard test condition.

Load Any device or appliance that uses electrical power (solar electricity in case of a PV system)

Maximum Power Point Tracker (MPPT) Impedance matching electronics used to hold the output of the PV array at its maximum value. Used with PV pumps, telecommunications, railway signalling, etc.

Mounting structure Metallic structures/frames used for mounting of PV components.

Parallel connection A method of interconnecting two or more electricity producing devices, or power using devices, such that the voltage produced or required is not increased, but the current is additive. Opposite of series connection.

Peak Watt or Watt peak The approximate amount of power a PV system produces at noon on a clear day (radiation = 1000 W/m^2) when the solar panel is in full sunlight.

Photovoltaic (PV) system A complete set of components for converting sunlight into electricity by the photo-electric process, including solar array and Balance of Systems.

Polycrystalline silicon (cell) Silicon solidified at such a rate that many small crystals have formed. The atoms within a single crystal are symmetrically arrayed, whereas in polysilicon crystals they are jumbled together.

Power conditioner The electrical equipment used to convert power from a PV array into a form suitable for subsequent use, as in supplying a household. A collective term for inverter, transformer, voltage regulator, meters, switches, and controls.

PV cell A semiconductor device that converts sunlight directly into electricity. All PV cells produce DC. Also called solar cell.

PV module A number of PV cells electrically interconnected and mounted together, usually in a common sealed unit or panel of convenient size for shipping, handling, and assembling into arrays.

PV array An interconnected system of PV modules that functions as a single electricity-producing unit. The modules are assembled as a discrete structure with common support or mounting.

Series connection A method of interconnecting devices that generate or use electricity so that the voltage, but not the current, is additive one to the other. Opposite of parallel connection.

Solar irradiation or insolation The energy received per unit area from the sun in a specified time period. [In this document, the time period is generally taken to be a day and the solar irradiation is expressed in MJ/m^2 per day or kWh/m^2 per day].

Stand alone PV system An isolated PV system not connected to a grid; may or may not have storage. But most stand-alone applications require a battery or other form of storage.

Tilt factor The ratio of solar irradiation incident on a tilted PV array to global irradiation. An angle at which the SPV panel is installed to get maximum solar irradiation.

Watt, wattage (W) A unit of electrical power, or an amount of work done in a unit of time. One ampere of current flowing at a potential of one volt produces one watt of power.

Watt-hour A quantity of electrical energy (electricity). One watt-hour is consumed when one watt of power is used for a period of one hour.

1

Annexe: List of PV system manufacturers and integrators

Agni Power & Electronics Pvt. Ltd
10/72
Bijoygarh
Calcutta 700 092

Bharat Heavy Electricals Ltd
Electronics Division
PO Box No. 2606
Mysore Road
Bangalore 560 026
Telephone: 080-624 283
Fax: 080-661 0137

Central Electronics Limited
4, Industrial Area
Sahibabad 201 010
Uttar Pradesh
Telephone: 8-771 918, 8-771 941
Fax: 8-771 843

Rajasthan Electronics and Instruments Ltd
2, Kanakpura Industrial Area
Jaipur 302 012
Telephone: 361 883/361 981
Fax: 0141-312 701

Geetanjali Solar Enterprises
P/14, Kasba Industrial Estate
Phase I, E M Bye Pass
Calcutta 700 078

Photon Energy Systems Ltd
Plot No. 775-K, Road No. 45
Jubilee Hills
Hyderabad 500 033
Telephone: 040-244 444, 216 152
Fax: 040-248 440, 216 059

Polyplex Corporation Limited
Ring Road
2, Kilokari, Opposite Maharani Bagh
New Delhi 110 014

Punjab Power Packs Ltd
B 98, Phase VIII
S A S Nagar (Mohali)
Chandigarh 160 059

Renewable Energy Systems
D-13A, Phase V
Industrial Development Area
Jeedimetla
Hyderabad 500 855
Telephone: 040-309 6676/309 6362
Fax: 040-309 5807/309 6879

RITIKA Systems Pvt. Ltd
B-279, Okhla Industrial Estate
Phase I
New Delhi 110 020
Telephone: 011-681 7369/681 5887
Fax: 011-647 7883

Shiv Shakti Electronics Pvt. Ltd
F-274, Flatted Factory Complex
Okhla Industrial Estate
New Delhi 110 020
Telephone: 011-684 0742
Fax: 011-684 9343

Vistar Electronics
42 A/1B, Erandawana
Nil Giri Apartments, Pune 411 038
Telephone: 0212-339267/331207
Fax: 0212-334 704

Sun Power
Suit 2E
52 B, Shakespeare Sarani
Calcutta 700 017

Sun Source (India) Ltd
First Floor, Ecotech
Navrang Centre, Swastik Char Rasta
Navrangpura
Ahmedabad 380 009

Suryovonics Limited
Devakripa
7-1-21 A, Begumpet
Hyderbad 500 016

Tata-BP Solar India Pvt. Ltd
Plot No. 78
Electronics City
Hebbagodi
Hosur Road
Bangalore 561 229
Telephone: 080-852 0081/852 0083
Fax: 080-852 0972/0974

Udhaya Semiconductor (P) Ltd
1, Pera Naidu Street
Peelamedu
Coimbatore 641 004

Webel-Sl Energy Systems Ltd
14B, 'Everest House'
46C, Chowringhee Road
Calcutta 700 071

Source. MNES. 1997. *Renewable Energy: Opportunities and Guidelines for Investors.* New Delhi: Ministry of Non-conventional Energy Sources, Government of India.

2

Annexe: List of financial institutions and intermediaries

Financial institutions

Indian Renewable Energy Development Agency Ltd
Core 4-A
East Court
Ist Floor
Indian Habitat Centre
Lodhi Road
New Delhi 110 003
Telephone: 011-460 2744, 464 2377
Fax: 011- 460 2855, 464 2376

Industrial Credit & Investment Corporation of India
ICICI Building
163, Backbay
Reclamation
Churchgate
Mumbai 400 020
Fax: 022-204 6582

Industrial Development Bank of India
IDBI Tower
Cuffe Parade
Mumbai 400 020
Fax: 022-218 0411, 218 1294

Industrial Finance Corporation of India
Bank of Baroda Building
16, Sansad Marg
New Delhi 110 001
Telephone: 011-332 0425
Fax: 011-332 3143

Industrial Reconstruction Bank of India
19, N S Road
Calcutta 700 001
Fax: 033-207 182

Infrastructure Leasing & Finance Scheme - Delhi
4th Floor, East Court Zone
Lodhi Road, New Delhi 110 003
Fax: 011-463 6657

Rural Electrification Corporation Ltd
Core 4, SCOPE Complex
7, Lodhi Road, New Delhi 110 003

Small Industries Development Bank of India
Nariman Bhawan
227, Vinay K Shah Marg
Nariman Point, Mumbai 400 021
Fax: 022-204 4448

Financial intermediaries

Care Well Corporate Service Ltd
308 Chetak Centre
1212, Ant Marg, Indore 452 001
Madhya Pradesh
Telephone: 0731-518 612, 527 224

Escorts Finance Ltd
N-6, Partap Building
Connaught Circus
New Delhi 110 001
Telephone: 011-331 3027, 335 1325
Fax: 011-331 1715

Hansuttum Finance Ltd
57-H, Connaught Circus
New Delhi 110 001
Telephone: 011-373 9656, 332 0876
Fax: 011-335 3944

Hindustan Financial Management Ltd
G-3, Siddarth, 96 Nehru Place
New Delhi 110 019
Telephone: 011-643 2161, 642 6354
Fax: 011-642 4267

Integra Capital Management Ltd
Integra House
9/2 Sarvapriya Vihar
New Delhi 110 016

Jamnadas Morarjee Finance Ltd
1101, Dalamal Towers
Nariman Point
Mumbai 400 021
Telephone: 022-285 6053
Fax: 022-282 5417

Lloyds Finance Ltd
601, Raheja Centre, 6th floor
Nariman Point
Mumbai 400 021
Telephone: 022-204 8297
Fax: 022-285 4474

Nagarjuna Finance Ltd
Nagarjuna Hills
Punjagutta
Hyderabad 500 482
Telephone: 040-207 4115

Prakash Leasing Ltd
No. 7 (49) 2nd floor
Kodava Somaji Building
1st Main Road
Vasant Nagar
Bangalore 560 052

Risk Capital & Technology Finance Scheme - Delhi
4th Floor, 2425 Lodhi Institutional Area
Lodhi Road
New Delhi 110 003
Fax: 011-469 2295

Tata Finance Ltd
Jiji House
Damodardas Sukhadwala Marg
Mumbai 400 001
Telephone: 022-207 4115
Fax: 022-207 0237

Wipro Finance Ltd
Shaista Centre
5 Papanna Centre
St Mark Road Cross
Bangalore 560 001
Fax: 080-527 091

Source. MNES. 1997. *Renewable Energy: Opportunities and Guidelines for Investors.* New Delhi: Ministry of Non-conventional Energy Sources, Government of India.

3

Annexe: List of state nodal agencies

Director
Rajasthan Energy Development Agency
C-33, Chandra Jyoti
Lajpat Marg, C-Scheme
Jaipur 302 001

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Winrock International - India

The Winrock International - India is a private non-profit organization headquartered in the US, with offices in over 40 countries, including India. Its activities are funded through grants, contracts, and contributions from public and private sources. The focus of the Renewable Energy Programme of the Winrock International is to accelerate the commercialization of renewable energy technologies in rural areas where there is an expressed need for development. The Winrock has developed a network of offices and in-country entities called Renewable Energy Project Support Offices (REPSOs). REPSOs understand local development issues and have the technical expertise to realize the full potential of renewable energy applied to these areas.

The Winrock International - India, a registered non-governmental organization (NGO), emphasizes development of local institutions and human resources. Currently, its programmes cover three sectors:

- renewable energy;
- agricultural productivity; and
- forestry and natural resource management, including water resources.

Its renewable energy programme builds knowledge and capacity through the implementation of specific activities, with support from an advisory board made up of prominent Indian leaders from the public, private, and NGO sectors. Its REPSO actively works to build cooperation between government decision makers, private companies, NGOs, and financial institutions among others, and encourages potential markets for renewable energy development. Based on the present status of the renewable energy sector and their immediate needs in India, the workplan focuses on:

- rural photovoltaic commercialization;
- cogeneration in the sugar industry;
- small hydro and wind projects;
- emerging technologies;
- financial advisory services; and
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About the book

From sunlight to electricity: solar photovoltaic applications is a compilation of information that gives the readers an overall understanding of the photovoltaic (PV) sector in India, designs and applications of specific devices and related benefits, finance, and policies. The document also discusses the PV technology programme in India, the issues therein, and its future directions. The information has been presented in a format that is easy for the readers to understand and apply. The readers will find the information given in this document useful in assessing the potential of such systems and in identifying appropriate agencies for financing such systems. It serves the interest of all the stakeholders in the PV sector, such as policy-makers, government officials, non-governmental organizations, and academic and research organizations.

About TERI

TERI is an autonomous, not-for-profit research institute established in 1974. TERI is actively involved in the fields of energy, environment, biotechnology, forestry, and the whole range of sustainable development issues. Over 300 professionals, drawn from a wide range of disciplines, work at TERI's headquarters in New Delhi as well as at its regional centres and field sites in India and overseas.

TERI's beliefs are centred on the merits of human civilization moving away from the use of fossil fuels on account of their finite availability and the harmful environmental effects of the entire fossil energy cycle. In general, the Institute is committed to (1) reducing all forms of waste, (2) promoting efficient use of raw materials and depletable resources, (3) protecting the environment, and (4) conserving natural resources. More specifically, its activities are geared to promoting large-scale use of renewable forms of energy, protecting the earth's ozone layer, mitigating the threat of climate change, and reversing the loss of forest cover and biodiversity, all of which transcend national boundaries and require solutions through global cooperation. TERI also takes a comprehensive view of development, wherein efficient use of natural resources and protection of the environment are seen as essential prerequisites for economic welfare.